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THE PERIODICITY OF SUN-SPOTS

By ARTHUR SCHUSTER

I have recently obtained some results which seem to bring us a step nearer to the elucidation of the problem of sun-spot variability. My investigations will shortly be published in full, and I may therefore confine myself at present to a brief statement of the results.

The method used in the reduction of the statistical data has been described in previous publications, but a few words of explanation may assist the reader in forming a judgment on the value of the results obtained. Briefly speaking the method consists in analyzing any regular or irregular disturbance by a process of calculation which operates on it exactly as a spectroscope operates experimentally on a luminous disturbance. Such a luminous disturbance emanating for instance, from a red-hot body would, if we could examine it before it enters the spectroscope, present to us an extremely irregular appearance, and at first sight it would probably not be possible to distinguish it from a similar disturbance emanating from a white-hot body, or even from a gas radiating a number of homogeneous waves. The spectroscope in analyzing the light gives us the means of representing diagrammatically the intensity of radiation corresponding to any wave-length, and such a diagrammatic representation is of use to us even when the spectrum is "continuous," inasmuch as it allows us to determine the distribution of intensity which is the characteristic property of the radiation.

By a process depending on Fourier's theorem we may do by calculation for any variation precisely what the spectroscope does for a luminous vibration. I obtain in this way a diagram represented by a curve drawn with periodic times or frequencies as abscissæ, and having as ordinates numbers proportional to the sums of the squares of the two Fourier coefficients. This sum I call the "intensity" of the period, and the whole diagram is called the "periodogram." I must lay special stress on the fact that I consider the method adapted to pick out the characteristic properties of a variation apart from any homogeneous constituents which it may possess. The climate of a locality would, for instance, in my opinion be represented in the clearest and most concentrated manner if the chief meteorological elements, such as rainfall, barometric pressure, and temperature, were represented in the form of the periodogram.

If the variation is such that homogeneous variations are mixed up with irregular changes corresponding to the continuous spectrum, the method advocated is probably the only one which can give decisive results, especially in connection with a theorem expressing the probability that the periodic variation is not of an accidental nature. The optical analogy is perfect, even to the extent that the periodogram shows all the defects due to incomplete resolution, such as the "diffraction bands" on either side of a true homogeneous period. To separate homogeneous from non-homogeneous variations, high resolving power is necessary, as in the observations of chromospheric lines. Resolving power in optics is due to the number of complete periods which at any time affect the disturbance at the focus of the observing telescope, and in precisely the same way resolving power in the periodogram is directly proportional to the number of periods included in the Fourier analysis. Hence the importance of using observations extending over as long a range of time as possible.

After these preliminary remarks, I turn to the main object of my communication. The data used were Wolf and Wolfer's sun-spot numbers, which give us sufficient information from the year 1749 to the present time. I have in addition used, wherever possible, the measurements of areas which for each synodic revolution of the Sun have been collected by the Solar Physics Com-

mittee of the British Board of Education from the year 1832 onward, and the areas measured from photographs at the Greenwich Observatory for each day of the year since January 1, 1883. I have convinced myself that these series form a sufficiently homogeneous whole, and that Wolf's sun-spot numbers may with sufficient accuracy be made directly comparable with the measurement of areas after multiplication with a factor which is found to be nearly constant.

The whole of the observations were treated collectively, but the complete interval of 150 years was also divided into two nearly equal portions, which were separately examined. At first sight the results obtained by a comparison of the two intervals of 75 years was exceedingly puzzling. While the observations beginning with about 1826 showed a nearly homogeneous variation of 11.125 years, this period seemed almost entirely absent between 1749 and 1826. Its place was during that interval taken by two important groups of periodicities, one of which had a periodic time of about 9.25 years, while the second had an average period of 13.75 years. The latter period was represented more nearly by what in spectroscopy is called a "band" extending from 13.25 to 14.25 years, but some of this want of definiteness may be due to the deficiency in observational data. For some time I was inclined to draw the conclusion that such periodicities as we observe are comparatively short-lived, and replaced by a number of others, which in their turn die out. A more detailed investigation, however, convinced me that the periodicities are, as regards the interval of time elapsing between successive maxima, extremely regular, occurring with what may prove to be astronomical accuracy. The key of the solution is, I believe, to be found in the overlapping of a number of periods, all of which are regular as regards time, but vary considerably as regards intensity, so that one or other may for a certain number of years become inactive. Their real existence is proved by the fact that whenever they reappear after a period of inactivity, the phase of the renewed periodic action fits in exactly with the continuation of the old period.

I have approached the questions without preconceived opinions, and my first impression, as already stated, tended toward a denial

of fixed periods extending over long ranges of time. It was while writing out my conclusions to this effect, in preparing for publication, that I felt the impossibility of explaining some of the facts brought out by the periodogram as due to accident only, and I was thus forced toward a conviction that the periodicities were real and perfectly definite. The proof of the statement—which if true, must profoundly affect the problems of solar physics—can not be given here in its entirety, but I may briefly state the character of the evidence which to me was convincing.

A periodicity of about 4.78 years runs through the whole of the observations. Its amplitude, being about one-sixth of that of the eleven-year period, is too great to be accounted for by accident. It appears separately in the series of Wolf's numbers, ranging from 1749 to 1826 and from 1826 to 1900. It also appears in the series depending on the measurement of areas. The phases of the period as determined from these series are in good agreement, and even while I was inclined to question the permanency of the eleven-year period, I never felt any doubt that during the whole length of 150 years this period has been acting. Its time, determined as accurately as possible from the combined records, was 4.81 years, but I believe that, if greater weight were given to the more recent and more complete observations, the number would be slightly reduced. I wavered a long time between 4.78 and 4.81, and cannot distinguish with certainty between them. As regards the main period, which has certainly given its character to the sun-spot statistics during the greater part of the last century, I find the period, as determined from the observations since 1826 alone, to be 11.125 years. This agrees well with Wolfer's estimate of 11.124, and Newcomb's investigation, which led to 11.13 as the most probable number.

If to the most accurate series of measurements of sun-spot areas, which begin in 1832, we apply a process the result of which is the elimination of the chief period, and draw a curve representing what is left, we find decided maxima during the years 1836, 1845, 1853, 1862, and 1870; the intervals being alternatively 9 and 8 years, or 8.5 years on the average. The periodogram based on Wolf's numbers for the complete interval 1749–1900 shows a decided maximum

of intensity for a periodicity of 8.25 years. Adopting this period provisionally, and disregarding all observations since 1826, we may use Wolf's series previous to that date for the determination of the phase of the period in question, and thus forecast the maxima for the subsequent interval. We thus obtain 1836.3; 1844.7; 1852.9; 1861.2; 1869.4, in almost exact agreement wth the above. The slight error of phase would be corrected by assuming the time to have been 8.32 years.

A period of about 13.5 years shows as a maximum of intensity in the periodogram for the complete interval. In connection with it the following facts seem remarkable. There are in Wolf's records three cases of successive maxima having an interval of between 13 and 14 years. They are: 1626.0–1639.5; 1816.4–1829.9; 1870.6–1883.9. Also the interval between 1639.5 and 1816.4 is thirteen times 13.61, and the interval between 1829.9 and 1870.6 is three times 13.57. Thus the maxima all fit in with a period of about 13.6 years, which, with varying intensity, seems to have run through the whole record of observations.

Not wishing to lay too great a stress on what may prove to be merely a numerical coincidence, I return to the three periods which have been determined with some accuracy. It was only after the periodic times had been independently determined that the following remarkable relationship between the numbers was discovered. Taking frequencies into consideration, we are led to form the reciprocals of the periodic times and thus find:

$$\frac{1}{11.125} = 0.08989$$

$$\frac{1}{8.32} = 0.12019$$

Adding up we find $$\frac{1}{4.76} = 0.21008$$

Hence the sum of the frequencies of two of the periods agrees within the possible errors with the frequency of the third period. But it is also found that the first two numbers are very nearly in the ratio of three to four, so that we may also express the three periodic times as subperiods of 33.375 years. Thus:

$$\tfrac{1}{3} \times 33.375 = 11.125$$
$$\tfrac{1}{4} \times 33.375 = 8.344$$
$$\tfrac{1}{7} \times 33.375 = 4.768$$

How far this connection is accurate or approximate is impossible to say at present, but the fact that the three periods which have been traced with a considerable degree of certainty should also bear a remarkable simple relationship to each other is worthy of note.

If we accept a period twice as long as that given above, we might account for some other periodicities of which at present the times are only approximately determined; thus $\frac{1}{5}\times 66.75$ would lead us to 13.34, in fair agreement with the period of 13.57 years which has been mentioned above. But the difference is greater than it should be, and at the present I do not wish to put forward the longer period as probable.

I wish, in conclusion, with all due reserve, to allude briefly to the more speculative side of the question. Though we justly keep the statistical problem distinct from theoretical considerations, yet a discussion of the possible causes which produce the periodicity of sun-spots may assist further investigations by suggesting definite problems. We must only take care that the statistics themselves are not affected, as is too often the case, by a theoretical bias which destroys their value.

The first question which occurs relates to the location of the origin of the periodical effect. Is it internal or external to the solar surface? At present this question can be answered only by an indefinite and instinctive feeling as to the relative probability of the two rival hypotheses. I have consistently advocated the external origin, chiefly because orbital revolution was the simplest solution of periodic effects having the length of period shown by the sun-spot activity. As far back as 1878[1] I suggested a meteoric origin of the sun-spot cycle, and pointed out the changes in the shape of the corona which run parallel with that cycle. In a paper[2] which for the first time proved the possibility of ionizing a gas by means of the electric discharge, I drew attention to the importance of this discovery in explaining such phenomena as the diurnal variation of terrestrial magnetism. In a lecture delivered before the Royal Institution[3] I supported the idea of an electric origin of the luminosity of the corona which had been previously put forward by Sir

[1] *Observatory*, **2**, 262. [2] *Proc. R. S.*, **42**, 371, 1887.
[3] *Proceedings of the Royal Institution*, 1891.

William Huggins, and gave reasons for believing that the substance of the corona is partly formed by matter thrown out from the body of the Sun. I specially pointed out the similarity of the shape of the corona at a time of minimum sun-spots to a kathode acting in a magnetic field.

In my introductory address before the Mathematical and Physical section of the British Association,[1] I asked the question:

> May not the periodicity of sun-spots and the connection between two such dissimilar phenomena as spots on the Sun and magnetic disturbances on the Earth be due to a periodically recurring increase in the electric conductivity of the parts of space surrounding the Sun? Such an increase might be produced by meteoric matter circulating around the Sun.

The experimental progress made since then has added enormously to our knowledge regarding ionization, and the electric origin of the coronal streamers is now, I believe, universally accepted. In addition to the electric effects, we have learned to take account of the repulsion due to radiation which was first applied by Fitzgerald to the explanation of comets' tails, and has recently been brought into the discussion of solar effects, by Arrhenius and others. The general idea seems to be that the Sun is discharging negative electricity, and therefore its own positive charge must be accumulating. This charge itself will be dissipated because nothing can keep it on the surface of a body as hot as the Sun, but its dissipation may be very much slower than that of the negative charge. We have here conditions which might set up secondary discharges in the electric field formed by the projected negative matter and the positive charge left behind. These discharges would, according to this hypothesis, cause the luminosity of the corona, in so far as this is not due to self-luminous solid or liquid matter or to scattered light. But the electric disturbances in the field surrounding the Sun must, as regards intensity, be variable according to the amount of existing ionization, and this ionization will be affected by the circulation of meteoric matter.

This brings us to a possible explanation of the periodic effects. Imagine a meteoric stream passing at perihelion within a few solar diameters from the Sun. If this stream in its circulation has picked

[1] *British Association Reports*, 1892, 367.

up, as probably it would, some of the negative ions which had previously been projected outward by the Sun, it would at perihelion affect the luminosity and shape of the corona, and would generally increase the electric conductivity in the neighborhood of the Sun. A meteoric stream having an orbital revolution of 11.125 years might cause effects which are periodic in that time. The manner in which the spot phemonena may be secondary effects of the coronal disturbances, which I consider to be the primary effect, need not be discussed here. In addition to the suggested fertilization by ions projected from the Sun and brought back by the meteor stream, even more powerful causes might be supposed to act, if, during the journey of the solar system through space these streams were to pick up radio-active matter which we may imagine to be distributed throughout space. The possibility that one and the same stream might be effective during three or four successive revolutions and then become sterile owing to its passage through a portion of space void of ionizing constituents would give a simple explanation of the variability in its activity. If the sun-spot changes could be represented by the superposition of a few detached periodic effects, we should be led to the consideration of several active meteor streams. The possible existence of more than one stream will probably not be denied by anybody. There is, however, a difficulty to be found in the numerical relationship between the periodic times. If we imagine that the periodic time of the hypothetical stream is 33.375 years, a time which I am told by Professor Turner is very nearly equal to that of the Leonids, we should have to conclude that the meteoric matter is to a great extent concentrated at three points, reaching perihelion at equal intervals. The 8.32 period would have to be accounted for by concentrations at four equidistant points, one of which would have to be coincident with one of the three belonging to the other system. Questions of stability could probably be made to account for a concentration of matter at regular intervals in the orbit, but the superposition of two or more systems seems to me to present great difficulties. The first of the relationships which has been pointed out may, however, be due to some cause analogous to the one which in sound produces combination tones. If there are two periodic causes, which we may represent by cos n_1t and cos n_2t, producing

effects which are not simply proportional to the cause, but partly also to the squares and higher powers, the effects will have a term depending on

$$(\cos n_1t+\cos n_2t)^2=1+\tfrac{1}{2}\cos 2\,n_1t+\tfrac{1}{2}\cos 2\,n_2t+\cos(n_1+n_2)t+\cos(n_1-n_2)t.$$

If $\cos n_1t$ and $\cos n_2t$ represent the eleven-year and eight-year period respectively, $\cos(n_1+n_2)t$ would represent a 4.78-year period and $\cos(n_1-n_2)t$ a period of $33\frac{3}{8}$ years. The latter period has often been put forward as suggested by the observations, though I cannot detect any observational evidence for it beyond the fact that the two sun-spot maxima in 1837 and 1870 were stronger than those immediately preceding or following. On the whole, the harmonic ratios formed between the numbers representing the periodic times of the three best-established sun-spot cycles seem to be a difficulty in the hypothetical explanation here put forward.

ULTRA-VIOLET ABSORPTION SPECTRA IN RELATION TO PHYSICO-CHEMICAL PROCESSES

By E. C. C. BALY AND C. H. DESCH

The fact that certain organic compounds exhibit banded absorption in the ultra-violet region of the spectrum was discovered by Hartley and Huntington in 1879.[1] The number of compounds submitted to examination since that time is very large, interest having been aroused in the subject from the fact that the nature of the absorption was soon found to bear an intimate relation to the chemical character of the compound. When this result was once established, the method was frequently and successfully employed to determine the constitution in doubtful cases.

Hartley and Huntington's method, which is still in use, consists in photographing a spark spectrum by means of a quartz spectrograph, after passing through a layer of a solution of the substance under examination. These authors found water and methyl and ethyl alcohols to be highly diactinic, transmitting all the rays as far as $\lambda = 2000$ Å. U. It is therefore possible to employ them as solvents for the organic compounds to be investigated. As source of light the spark spectrum of an alloy of tin, lead, cadmium, and bismuth is employed. This spectrum contains a considerable number of lines fairly equally distributed over the blue and ultra-violet regions, and it is therefore easy to detect the presence of absorption, and to measure its limits by observing whether any lines or groups of lines are missing.

In studying questions of constitution, it is not sufficient to determine the position of the absorption band in any given case; it is also required to know the way in which the selective absorption varies with changes in the concentration of the solution. For this purpose a series of photographs of the spark spectrum is taken through layers of varying thickness of the solution, the process being continued until complete transmission is obtained. The

[1] *Phil. Trans.*, **170**, 257, 1879; *Proc. R. S.*, **31**, 1, 1880.

results are expressed graphically in the form of a curve, the oscillation-frequencies of the limits of absorption being plotted against the concentrations, and the curve drawn through the points so obtained. It is the form of these curves, called by Hartley curves of molecular vibrations, which is of importance in relation to the chemical constitution.

It has been found that there are, broadly speaking, two types of ultra-violet absorption spectra, one in which the absorption is perfectly general, all rays above a certain oscillation-frequency being absorbed, the other selective, showing one or more distinct absorption bands. The majority of the aliphatic compounds belong to the first class, while aromatic compounds generally exhibit selective absorption. In both cases, however, there are exceptions to the general rule, some of which are considered in the present paper.[1]

We have been led to consider the meaning of the ultra-violet absorption spectra by some investigations which we have recently carried out on aliphatic compounds exhibiting tautomerism, of which acetylacetone and ethyl aceto-acetate are the types.[2] Although containing only open carbon chains, these compounds show marked banded absorption in solution. Their study presents a special interest from the fact that it is possible to investigate the bands without the complications introduced by the presence of an aromatic nucleus.

We have adopted Hartley's method of work, with certain modifications. In place of the electric spark between electrodes of an alloy as a source of illumination, we have employed an arc between iron poles. This reduces the length of exposure considerably when photographing the spectra, and from the great richness in lines of the iron arc spectrum the accurate determination of the limits of absorption is greatly facilitated. An adjustable cell has been used to contain the absorbing solutions. This consists of two glass tubes, one of which fits loosely into the other. Both tubes have a flange at one end, which is ground flat and at right angles to the axis, and on each flange a quartz plate is cemented. A broad

[1] For a summary of the results obtained by various workers with ultra-violet absorption spectra, see *Brit. Assoc. Rep.*, 1901, 225; and Kayser, *Handbuch der Spectroscopie*, Leipzig, 1905, Vol. III, Chap. 3 (compiled by Professor Hartley).

[2] *Chem. Soc. Journ.*, **85**, 1029, 1904.

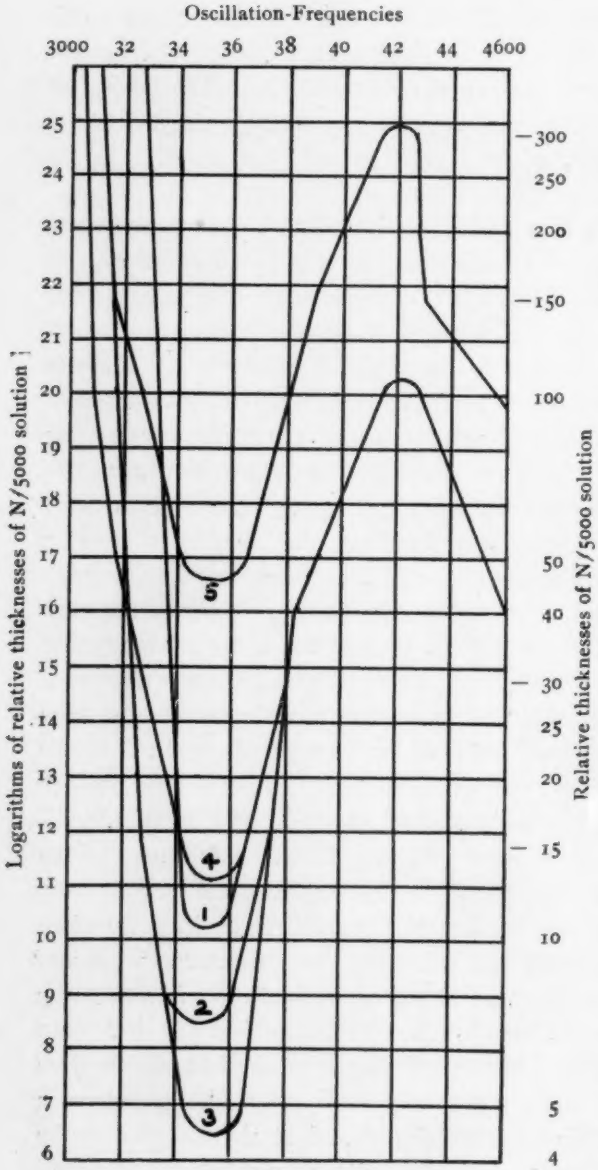

FIG. 1

Curve 1. Acetylacetone.
2. *Be* derivative.
3. *Al* derivative.
4. *Th* derivative.
5. Methylacetyl acetone.

india rubber band is slipped over the open end of the outer tube, and through this the inner tube slides freely, making a water-tight joint. A bulb-tube sealed on to the outer tube serves to take up the excess of solution as the inner tube is pushed inward, and a millimeter scale etched on the glass enables the thickness of the layer of solution to be read off directly. The use of such an adjustable cell is obviously more convenient than that of a number of cells of fixed thickness.

In actual practice, one tenth of a milligram-equivalent of the substance is dissolved in 50 cu. cm of the solvent—usually absolute alcohol, but in certain cases distilled water. The solution is put

into the absorption cell, and the iron spectrum is then photographed successively through 35, 30, 25, 20, 17, 15, 12, 10, 8, 6, 5, and 4 mm layers, and if necessary the same thicknesses are again employed after diluting the solution to ten times the original volume. It is found that the whole absorption band can, as a rule, be traced by examining in this way solutions of one five-hundredth and one five-thousandth normal concentration. In this way a complete record of the absorption is obtained over a range of from 4 to 350 mm thickness of a five-thousandth normal solution.

We have employed a new method of exhibiting the results graphically. The oscillation-frequencies of the limits of transmission are, as usual, taken as abscissæ, but instead of the concentrations or thicknesses of solution, the ***logarithms*** of the thickness are plotted as ordinates. This method has the great advantage that a given relative change of concentration is represented by the same change of ordinates in any part of the diagram; so that an absorption band which, for example, just persists while the concentration is halved, occupies the same space when plotted, whatever the absolute concentration may be. This persistence is a very characteristic function of a band, and has great theoretical importance.

The first compounds which we investigated were acetylacetone $CH_3-CO-CH_2-CO-CH_3$ and ethyl aceto-acetate, $CH_3-CO-CH_2-CO_2Et$, and their respective metallic derivatives. Acetylacetone itself, and its beryllium, aluminium, and thorium derivatives, were found to give very similar spectra, although differing somewhat in the breadth and persistence of the absorption band (Fig. 1). On the other hand, ethyl aceto-acetate gave only a slight general absorption without any trace of a band, while its aluminium derivative gave a banded spectrum almost identical with that of acetylacetone. This seemed to accord with the view that the band is due to the enolic grouping $-CH:C(OH)-$, since the results of Perkin,[1] Brühl,[2] and Drude[3] have made it probable that free acetylacetone has the enolic, and ethyl aceto-acetate the ketonic, structure. The metallic derivatives must then have the enolic structure, the metal being attached to the oxygen atom.

[1] *Chem. Soc. Journ.*, **61**, 800, 1892.

[2] *Ber.*, **27**, 2378, 1894. [3] *Ibid.*, **30**, 940, 1897.

Further consideration showed, however, that this explanation could not be considered satisfactory. There is no *a priori* reason why an enolic compound should exert banded absorption, since no band is produced by the presence of a double bond or of a hydroxyl group. Neither the ketonic $-CH_2-\underset{O}{\overset{C}{\|}}-$ nor the enolic $-CH=\underset{OH}{\overset{C-}{|}}-$ grouping should therefore give rise to a band. In order to test this point we examined the $O-$ and $C-$ethyl derivatives of ethyl aceto-acetate, namely ethyl $\beta-$ethoxycrotonate $CH_3-\underset{OEt}{\overset{C}{|}}=CH-CO_2Et$, and ethyl ethylacetoacetate $CH_3-\underset{O}{\overset{C}{\|}}\cdot CHEt-CO_2-CH_3$, and found that the enolic compound exerts only general absorption without any trace of a band, while the ketonic compound is practically completely diactinic. As it has been shown by Hartley and others that the replacement of a hydrogen atom by a light alkyl group does not modify the type of spectrum, these results leave no doubt that the spectra of the pure enolic and the pure ketonic modifications show no band. Further, no band is given by a mixture of the two isomeric ethyl derivatives. The purely ketonic acetonylacetone $CH_3\cdot CO\cdot CH_2\cdot CH_2\cdot CO\cdot CH_3$, and the purely enolic ethyl ethoxyfumarate, $CO_2Et\cdot C\ (OEt) : CH\cdot CO_2Et$, also show only general absorption without indication of a band.

It seemed probable therefore, that the absorption was not to be attributed to any definite molecular structure, but rather to the existence of dynamical isomerism between two modifications of the compound present in the solution. The evidence for the existence of isomerides in a state of dynamical equilibrium in solutions has recently been summarized by Lowry,[1] and it is now generally admitted that the chemical and physical properties of so-called "tautomeric" substances are best explained by the assumption of such dynamical isomerism. Our results seemed to justify the view that the absorption bands observed were connected with the intramolecular change from one modification to the other. In order to test this explanation, we have investigated the action of alkalis and of acids on the absorption spectra. It was found by Lapworth and Hann[2] that the final state

[1] *Brit. Assoc. Rep.*, 1904, 193. [2] *Chem. Soc. Journ.*, **81**, 1508, 1902.

of equilibrium in the cases examined by them was independent of the presence of a catalytic agent; but that the velocity of transformation of one modification into the other, and therefore the rate at which equilibrium was reached, was in general accelerated by the presence of bases and retarded by that of acids. The final state being unaffected by the catalytic agent, this implies that the direct and reverse changes are equally accelerated or retarded. If, then, the absorption bands are due to an intramolecular change, the acceleration of this change by addition of a catalytic agent should show itself in the increased persistence of the band, and a retardation of the change by a diminution of the persistence. Experiment confirms these conclusions. The absorption of ethyl acetoacetate is shown in Fig. 2, curve 1; curve 7 being obtained on addition of

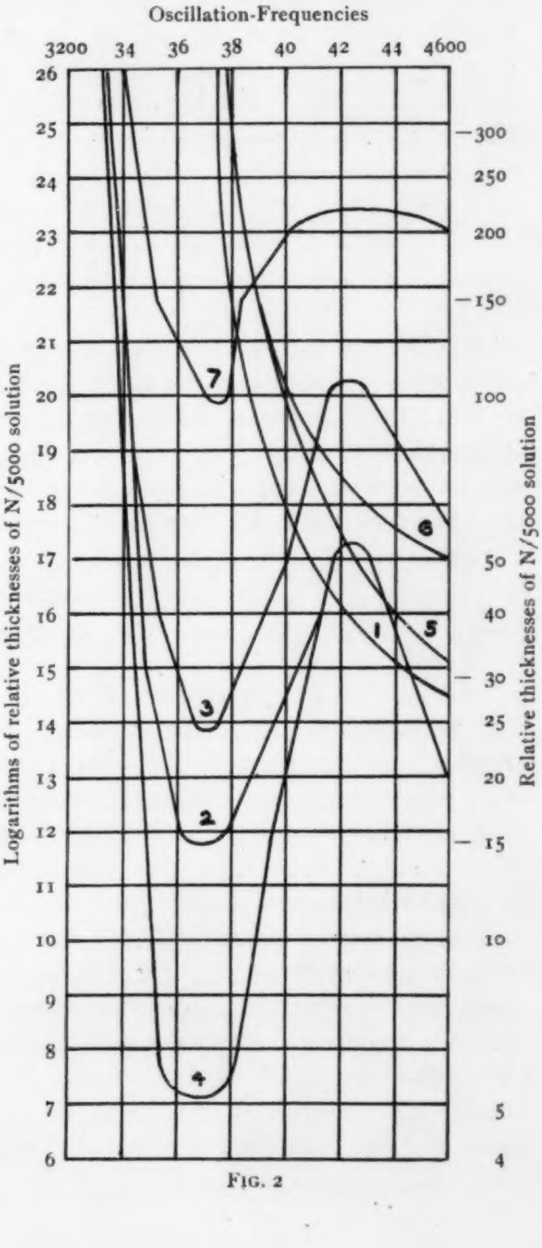

FIG. 2

0.5 equivaalent of sodium hydroxide, curve 3 with 1 equivalent, and curve 4 with an excess of the alkali. Curve 2 shows the absorption of the aluminium derivative. This figure indicates the value of the logarithmic method of plotting, for the persistence of the band is directly proportional to its height on the ordinates, and it will be noticed that this persistence increases with an increasing proportion of alkali. In the presence of an excess of sodium hydroxide, the band is more persistent than that given by the pure aluminium derivative, which is a striking fact in support of our views. The retarding action of hydrochloric acid is also shown in Fig. 2, curves 5 and 6 being obtained on the addition of a trace and of an excess of this acid respectively. These results indicate that ethyl acetoacetate is not entirely ketonic, but that there is an equilibrium with a small quantity of the enolic modification. This conclusion is also in accordance with the known physical and chemical properties of the ester.

A similar but even more marked retarding action of hydrochloric acid was observed in the case of ethyl β–aminocrotonate in which oscillation between the modifications $CH_3 \cdot \overset{C}{\underset{NH_2}{|}} : CH \cdot CO_2Et$ and $CH_3 \cdot \overset{C}{\underset{NH}{\|}} \cdot CH_2 \cdot CO_2Et$ is possible. In this case the persistence of the band is steadily diminished by successive additions of acid.

We have recently[1] extended this investigation by examining several other compounds, including ethyl acetylsuccinate, $CH_3 \cdot CO \cdot CH(CO_2Et) \cdot CH_2 \cdot CO_2Et$, ethyl diacetylsuccinate, $CH_3 \cdot CO \cdot CH(CO_2Et) \cdot CH(CO_2Et) \cdot CO \cdot CH_3$, ethyl benzoylacetate, $C_6H_5 \cdot CO \cdot CH_2 \cdot CO_2Et$, ethyl oxaloacetate, $CO_2Et \cdot CO \cdot CH_2 CO_2Et$, ethyl acetonedicarboxylate, $CO_2Et \cdot CH_2 \cdot CO \cdot CH_2 \cdot CO_2 Et$, ethyl benzoylsuccinate, $C_6H_5 \cdot CO \cdot CH(CO_2Et)CH_2 \cdot CO_2Et$, and benzoylacetone, $C_6H_5 \cdot CO \cdot CH_2 \cdot CO \cdot CH_3$, and certain of their metallic derivatives. (For the sake of brevity, only the ketonic formula is indicated in each case.) Of these, only three, namely, benzoylacetone, ethyl benzoylacetate, and ethyl benzoylsuccinate, exhibit absorption bands in the free state, but a band is in each case produced by the addition of sodium hydroxide.

[1] *Chem. Soc. Journ.*, **87**, 766, 1905.

It will be seen on reference to Fig. 1 that the oscillation-frequencies of the absorption bands given by acetylacetone and its metallic derivatives are almost identical. We have obtained similar results in our more recent work, and we find generally that the band of the metallic derivative is usually shifted slightly toward the red as compared with the free substance, but that the amount of shifting is not the same in all the compounds examined, nor does it bear a simple relation to the mass of the metallic atom replacing hydrogen. It is rather such as might be expected from the small increase in the total mass of the molecule.

It is evident from a consideration of these results that some oscillation or free period must exist in connection with the reversible transformation of one tautomeric form into the other, which is synchronous with the oscillation of the light rays absorbed. It is not possible that this vibration can be the vibration of the labile atom itself, for, apart from the fact that the oscillation-frequency of the absorption band is found to stand in no direct relation to the mass of this labile atom, it is also noteworthy that the frequency is far greater than that usually attributed to atomic motions. We are therefore forced to conclude that the absorption of light is due to the transformation which is expressed chemically by a change of linking. In the case of the keto-enol tautomerides under consideration, this change is expressed by the equation:

$$\underset{\displaystyle OH}{-CH=\overset{}{\underset{|}{C}}-} \rightleftharpoons -CH_2-\underset{\overset{\|}{\displaystyle O}}{C}- \;.$$

We may represent this more simply as being due to the existence of a transitional phase:

$$-\overset{*}{C}H-\underset{\underset{\displaystyle O^*}{|}}{\overset{*}{C}}-$$

in which the asterisks indicate that the atoms so marked are actually in the state of changing their linking.

In seeking to form a physical conception of the process involved, several facts, derived from the results of previous workers in this field, have to be taken into consideration. A study of the data obtained by Hartley and others, and summarized in Professor

Kayser's *Handbook,* Vol. III, Chap. 3, shows that an absorption band in the ultra-violet region of the spectrum is only shown by compounds having a possibility of tautomerism. Such tautomerism is not necessarily due to the presence of a labile atom, but may be of the same order as that occurring in ring compounds of the aromatic type, in which a reversible change of linking may take place periodically. The absorption bands of all the simpler tautomeric molecules, that is to say, in which open chains only are concerned in the change of linking, have approximately the same frequency. An increase in the mass of the molecule causes a decrease in the oscillation-frequency of the band, which is consequently displaced toward the red end of the spectrum; but this displacement is only a small fraction of the whole frequency, and the approximate constancy of the position of the band throughout this large class of compounds points strongly to the existence of some condition common to the whole group, to which the absorption is to be ascribed. Further, Hewitt has shown[1] the intimate relation existing between tautomerism or dynamic isomerism and fluorescence, from which it appears that compounds undergoing labile change of this type are in certain cases capable of selecting certain radiations and of emitting them at a different frequency. The experiments of Armstrong and Lowry[2] also indicate that dynamic change may even be accompanied by the emission of visible radiations, in the phenomena of triboluminescence.

No explanation has yet been brought forward of the whole of these facts. In order to obtain such an explanation we believe it to be necessary to examine the phenomena, not merely from the chemical, but also from the physical point of view. The facts connected with the nature of emission spectra, the grouping of spectral lines into series, the action of a magnetic field on radiation (the Zeeman effect) and the phenomena of radioactivity, are all co-ordinated by means of the hypothesis which regards the chemical atom as a system of electrons. On this hypothesis, the atom is considered to be a system of extremely small particles carrying a negative electrical charge, revolving in orbits about a common center of attraction. One form of this hypothesis, which appears to have

[1] *Zeit. physical. Chem.*, **24**, 1, 1897. [2] *Proc. R. S.*, **72**, 258, 1903.

special advantages from the spectroscopic point of view, regards the system as being exactly comparable with that of the planet *Saturn*, electrical being substituted for gravitational attraction. That is to say, the small, negatively charged electrons are considered to revolve in a belt about a larger, positively charged central body.[1] The phenomena of radiation are well explained by the regular or disturbed motions of such a system. The arrangement assumed by J. J. Thomson is somewhat similar.

On such a hypothesis, chemical combination between two atoms results in the transference of one or more electrons from one atom to another. One or more Faraday tubes of force are thus produced between the two atoms, each tube representing the chemist's single bond of affinity. If by any means a rearrangement of the Faraday tubes is brought about, a vibrational disturbance is set up in the electron systems. The change of linking between different atoms involved in tautomeric or isodynamic change implies the repeated making and breaking of Faraday tubes, owing to the transference of electrons from one atom to another. If Hewitt's explanation of the origin of fluoresence be accepted, it follows that the vibrational disturbances thus set up by isodynamic change are of the same order of frequency as light-waves. In accordance with the principle of resonance, therefore, a system in which such vibrations are going on will absorb light rays of that period. Since the vibrations will not be synchronous, the absorption band thus produced will have an appreciable breadth.

By means of this hypothesis, the phenomena of absorption are brought into the same category as those of radiation. In the case of luminosity produced by heat or by electric action, the origin of the luminosity lies in the rapid changes of stress or electric field to which the molecules or atoms are subjected. In the case of absorption by tautomeric substances, the disturbances of the electrons are due to changes of linking within the molecule. The presence of a labile atom is not necessary, as the alternating changes of linking in a ring of atoms of the benzenoid type gives rise to absorption of the same kind.[2] The comparatively small displacement of the absorp-

[1] Nagaoka, *Nature*, **69**, 392, 1904.

[2] For an experimental study of this case, see Baly and Collie, *Chem. Soc. Journ.*, **87**, 1332, 1905; Baly and Ewbank, *ibid.*, 1347, 1355.

tion band by an alteration of the mass of the molecule is in accordance with our view. An increase in the mass of matter in the immediate neighborhood of the vibrating electrons has the effect of retarding their motions, the oscillation-frequency thus becoming less. This is well shown in the case of the emission spectra of the elements. Closely related chemical elements show spectra of similar structure, but the spectral series show a displacement toward the red, that is, a decrease of frequency, with increasing atomic mass. For example, the first members of the principal series of the alkali metals are represented by the following equations of Kayser and Runge, n being the oscillation-frequency and m the number of the line in the series (3, 4, 5, etc.):

$$\text{Lithium,} \quad n=43584.75-\frac{133669}{m^2}-\frac{1100084}{m^4} ;$$

$$\text{Sodium,} \quad n=41542.51-\frac{130233}{m^2}-\frac{800791}{m^4} ;$$

$$\text{Potassium,} \quad n=35086.55-\frac{126983}{m^2}-\frac{625318}{m^4} ;$$

$$\text{Rubidium,} \quad n=33762.11-\frac{125531}{m^2}-\frac{562255}{m^4} ;$$

$$\text{Cæsium,} \quad n=31509.31-\frac{125395}{m^2}-\frac{486773}{m^4} .$$

The first term of the above equations, or the value of the oscillation-frequency when $m=\infty$, called the convergence frequency, is seen to decrease with increasing atomic weight. This is generally true of emission spectra. Similar relations have been observed in absorption spectra in the visible region, as in the case of didymium salts, the absorption bands of which were shown by Bunsen[1] to be displaced toward the red with increasing molecular weight. A similar displacement is well known in the case of organic dyes, which become increasingly blue in color as heavy groups are introduced into the molecule; that is to say, the absorption bands are displaced toward the red end of the spectrum.

The bearing of the facts just described on the theory of solutions may next be considered. We have shown that solutions of both the sodium and the aluminium derivatives of ethyl acetoacetate contain

[1] *Pogg. Ann.*, **128**, 100, 1866.

the enolic and ketonic modifications in dynamical equilibrium; that is the metallic atom is alternately linked to the carbon and to the oxygen atom. But from the chemical point of view there is an important difference between the two derivatives. The sodium compound is readily ionized, and in dilute solutions is almost completely hydrolysed into sodium hydroxide and free ethyl acetoacetate. The aluminium derivative, on the other hand, undergoes dissociation and hydrolysis only to a very small extent.[1] The absorption spectrum is not therefore dependent on either ionization or hydrolysis. In this connection the work of Hartley on the ultra-violet absorption spectra of metallic nitrates[2] is of great importance. Hartley showed that the metallic nitrates exhibit an absorption band in dilute aqueous solution, and that the position of this band depends on the mass of the metal. This is the case even in solutions which on the ordinary hypothesis are almost completely dissociated, as shown by their electrical conductivity. There is therefore direct evidence of a physical connection between the anion and cation in such solutions. Even without the evidence furnished by Hartley's results, the difficulty felt in forming any distinct physical conception of a solution in which the ions have an entirely independent existence points to the same conclusion. The physical objections to the hypothesis of independent ions have been clearly stated by Fitzgerald in his Faraday lecture.[3] A theory of solution must therefore take into account the persistence of a physical connection between the ions, even in the most dilute solutions.

To take the simplest case, that of a binary salt dissolved in water, the two atoms composing the salt are connected by means of a Faraday tube of force, as stated above. On bringing the system into the presence of a large number of molecules of water, as in the process of dissolution, the atoms are drawn apart, and the Faraday tube between them is correspondingly lengthened, without, however, being broken. The force needed to separate the atoms, or ions as they may conveniently be called, is furnished by the attraction of the solvent.

[1] Hantzsch and Desch, *Ann.*, **323**, 1, 1902.

[2] *Chem. Soc. Journ.*, **81**, 571, 1902; **83**, 221, 1903.

[3] *Ibid.*, **69**, 885, 1896.

The solvents which produce this effect, the so-called "ionizing solvents," are those possessing marked residual affinity, such as water, alcohol, liquid sulphur dioxide, and ammonia. That the chemical affinity of the solvent for the dissolved substance plays an important part in the phenomena of solution is becoming increasingly obvious, whatever view may be taken of the way in which this affinity acts. But the attraction of the solvent is not merely exerted on the molecule as a whole, but also on its components separately. The conception of such an attraction of the solvent for the ions is involved in the use of the expression "hydrated ions."[1] An ionizing solvent is one the affinities of these for the dissolved molecule and its component ions are such as to bring about this separation of the atoms and lengthening of the Faraday tubes. When this lengthening reaches a certain critical value, an interchange of ions between molecules approaching one another in the solution becomes possible. We assume that no such interchange is possible so long as the Faraday tubes are in all cases below the critical length. The interchanges may be represented diagrammatically as taking place in the following way:

$$\begin{array}{ccc} \begin{matrix} A & B \\ | & | \\ B & A \end{matrix} & \qquad \begin{matrix} A) & (B \\ B) & (A \end{matrix} \qquad & \begin{matrix} A-B \\ B-A \end{matrix} \\ & \text{Transition phase} & \end{array}$$

On this view, a "completely dissociated" dilute solution of a salt is not one in which the ions are moving about independently of one another, but is one in which the Faraday tubes have been lengthened sufficiently in the case of every molecule present to allow of free interchange. A "partially dissociated" solution is one in which a greater or less proportion of the Faraday tubes exceed the critical length, but not the whole. Physical properties such as the electrolytic conductivity and the osmotic pressure furnish a means of determining the proportion of molecules in this state.

In solutions of tautomeric substances we have the Faraday tubes or bonds connecting the labile atom with the rest of the molecule lengthened to such an extent as to allow of these atoms changing

[1] See, for a summary of this question, Walden, *Zeit. phys. Chem.*, **39**, 539, 1902; Baur, "Von den Hydraten in wässeriger Lösung," *Ahrens Sammlung*, 1903; Lowry, *Trans. Faraday Soc.*, **1**, 197, 1905.

from one position to another within the same molecule. We have then a kind of internal ionization, with the labile atom as a potential ion. The making and breaking of the Faraday tubes accompanying this change causes the oscillatory disturbances to which we have attributed the absorption bands. The lengthening of the tubes of force may be insufficient to allow of free interchange between different molecules, so that "ionization" as shown by electrical conductivity, etc., may be absent, as in the case of ethyl acetoacetate and its aluminium derivative, and many similar compounds. It is well known that in the case of the tautomeric aliphatic compounds the replacement of a labile hydrogen or metallic atom by an alkyl group destroys the tautomerism. This is entirely in accordance with the fact that alkyl ions are unknown. The attraction of water or alcohol appears to be insufficient to lengthen the Faraday tubes connecting alkyl or similar groups with the rest of the molecule to a sufficient extent to allow of either internal or intermolecular interchange. Even in such solutions as these the molecules must be regarded as in a state of strain, and it is probable that a very small increase of tension would suffice to lengthen the Faraday tubes beyond the critical value. Such an increase may conceivably be produced by the introduction of another substance into the solution. The resulting change of physical and chemical conditions may bring about the lengthening to such an extent that the critical value is overstepped and interchange takes place. This is a possible explanation of the numerous reactions between substances in solution, especially in organic chemistry, which appear to take place between ions, although the external evidences of ionization, such as the presence of electrolytic conductivity, are absent.[1] Several grades of this ionic separation must thus be considered to exist.

Firstly, there are solutions, such as that of mercuric cyanide in water, where the lengthening of the Faraday tubes is insufficient to allow of interchange; the salt is therefore spoken of as non-ionized.

The second grade is represented by the tautomeric compounds containing a labile atom, intramolecular interchange thus being possible. Thirdly, we have the condition existing in ordinary salt solutions, in which the interchange of ions takes place more or less

[1] See especially Kahlenberg, *Journ. Phys. Chem.*, **6**, 1, 1902.

freely. The group of complex salts may be considered as a subdivision of this class. A complex salt such as $KAg(CN)_2$ undergoes dissociation into K and $Ag(CN)_2$ ions; that is to say, interchange of these ions takes place freely. In addition to this, the solvent tends, especially in dilute solutions, to separate the components of the complex ion sufficiently to permit of interchange between them, so that we have evidence of the presence of Ag and CN ions in the solution. Viewed in this way, the differences between dissociated and undissociated compounds in solution become differences of degree and not of kind. There is no discontinuity in the action of the solvent, which always tends to separate the ions, thus lengthening the tubes of force between them.

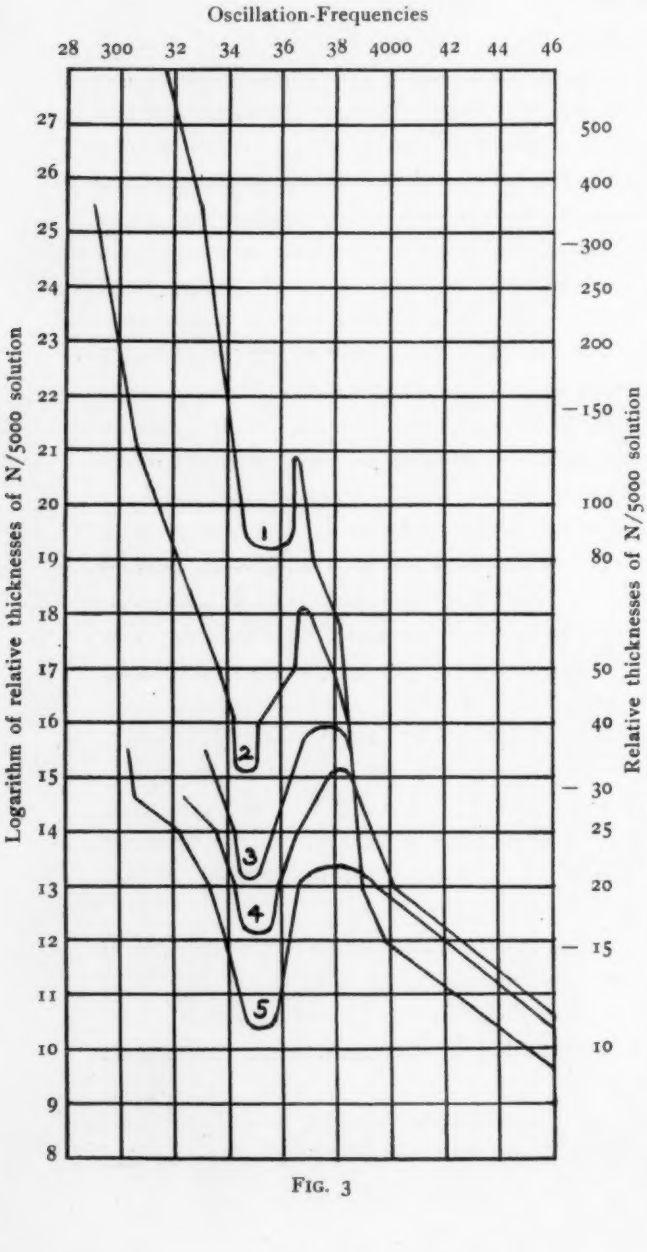

FIG. 3

Whether this results in the formation of an electrolytically conducting solution, showing the ordinary properties of ionization, depends upon whether all or some of the tubes of force are extended beyond the critical length at which interchange becomes possible, or not.

One consequence of these views in the case of open chain tautomeric compounds can be put to the test experimentally. It has been said already that the persistence of the absorption bands given by these compounds is a measure of the number of molecules undergoing transformation at any moment. That is to say, it is a measure of the number of cases in which the labile atom is separated from the rest of the molecule by a distance exceeding the critical value. There should therefore exist for each tautomeric compound a maximum value of this persistence, corresponding with the lengthening of all the bonds beyond this critical value, so that free interchange is taking place. Now, it was shown above that the addition of sodium hydroxide increases the persistence of the bands; that is to say, it favors the lengthening of the tubes of force, and consequently facilitates interchange. Successive additions of the accelerating reagent may therefore be expected to increase the persistence of the band until a maximum is reached. We have tested this conclusion in the case of ethyl benzoylsuccinate[1] observing the absorption spectrum of solutions of this compound alone and in the presence of 1, 10, 20, and 100 equivalents of sodium hydroxide. The limits of persistence observed are as follows:

	Free Ester	Ester with 1 Eq. *NaOH*	Ester with 10 Eq. *NaOH*	Ester with 20 Eq. *NaOH*	Ester with 100 Eq. *NaOH*
Absorption band begins at.....	120 mm	63 mm	40 mm	31.7 mm	21.9 mm
Absorption band ends at......	83.2 mm	34.7 mm	20 mm	15.2 mm	10.4 mm
Change of dilution over which the absorption band persists.	30.7%	44.9%	50%	52%	52.5%

The thicknesses given refer to a 1/10000 normal solution of the ester. The complete absorption curves are shown in Fig. 3, in which curve 1 is that of the free ester, and curves 2, 3, 4, and 5 are those of the ester in the presence of 1, 10, 20, and 100 equivalents

[1] *Chem. Soc. Jour.*, **87**, 766, 1905.

of $NaOH$ respectively. It will be seen that the maximum is practically reached on the addition of 20 equivalents, an increase of the alkali to 100 equivalents only bringing about an increase of persistence of 0.5 per cent.

CONCLUSIONS

The following conclusions may be drawn from the experiments described:

1. In the case of solutions of the aliphatic tautomeric substances neither the pure ketonic nor the pure enolic modification gives an absorption band in the ultra-violet region.

2. In solutions of the concentrations considered by us the pure ketonic modification is almost completely diactinic, while the pure enolic modification exerts a small general absorption.

3. An absorption band is obtained only when both modifications are present in a state of dynamical equilibrium with one another.

4. The persistence of the absorption band is a measure of the number of molecules in the changing state at a given time. It is probable that the number changing must be considerable in order to produce sensible absorption.

5. In the cases examined the persistence is increased by the addition of alkali hydroxide and diminished by the addition of acid.

6. Successive additions of alkali increase the persistence until a maximum value is reached, beyond which further additions produce no further effect.

7. These results are independent of the ionization or hydrolysis of the compounds examined.

8. The oscillation frequency of the absorption band varies slightly with the total mass of the molecule, but is not directly dependent on the mass of the labile atom.

9. The absorption band is due to the change of linking accompanying the reversible change from one tautomeric modification to the other, and its production may be explained by means of the conception of the atom as a system of electrons.

10. The change of linking may be due either to the motions of a labile atom or to the internal changes in a benzenoid ring, the same type of absorption band being produced in both cases.

11. The action of the solvent may be regarded as tending to lengthen the bond of attraction or Faraday tube of force between the atoms, until, when a certain critical length is reached, interchange of atoms from one position to another within the molecule becomes possible. Catalytic agents act by lengthening or shortening the tubes of force.

12. In the case of "ionized" solutions the lengthening of the tubes of force exceeds a value at which interchange between different molecules becomes possible. The "degree of ionization" is a measure of the number of interchanges taking place. When the length of the bonds is below the critical value, there is no evidence of ionization, but the critical length may be so nearly approached that a small external influence will cause it to be exceeded.

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PRELIMINARY RESULTS OF UNITED STATES NAVAL OBSERVATORY ECLIPSE EXPEDITION IN 1905

By COLBY M. CHESTER

The U. S. Naval Observatory expedition to observe the total solar eclipse of August 30, 1905, was sent out in connection with a squadron of three vessels detailed by the Navy Department, with the superintendent of the Observatory, Rear-Admiral C. M. Chester, U. S. N., as commander-in-chief. Three principal stations were established: one near the central line at Daroca, on the highlands of the Spanish peninsula, at an altitude of about 2500 feet; one near the southern edge at Porta Coeli, a few miles from the Mediterranean coast of Spain, at an altitude of about 1000 feet; and one near the central line at Guelma, Algeria, about 40 miles from the coast, at an elevation of about 1500 feet. At Daroca Professor of Mathematics W. S. Eichelberger was in charge. At Porta Coeli Professor of Mathematics F. B. Littell was in charge of the installation, to be relieved by Lieutenant-Commander E. E. Hayden when the whole party of observers was assembled. Rear-Admiral Chester took station here during the eclipse. At Guelma Captain J. A. Norris was in charge.

When it was decided to equip three stations completely for photographing the corona with long- and short-focus cameras, and for spectroscopic work, it was found that it would be necessary to supplement and remodel the available apparatus on hand to a considerable extent. A new 7½-inch lens of 65 feet focal length was made by Brashear. Two new cœlostats, designed by Mr. Dinwiddie, were made by William Gaertner & Co., of Chicago. The rest of the new apparatus required was constructed at the Observatory under the direction of Mr. Dinwiddie. Three polar axes were made 10 feet long, of steel and iron construction, so arranged that the cameras were hung within the frame. The tubes of the cameras to be used on the polar axes consisted of similar latticed iron framework lined with black velvet and covered with sheeting soaked in a mixture of linseed oil and lampblack. One new grating-holder was made, supporting the grating

from both sides of the camera frame, which was also of steel construction. Three portable dark-rooms for developing were constructed; also three portable dark-rooms for the long-focus cameras, and three tubes similar to the one used by Professor Barnard in Sumatra in 1901, but with ventilating doors on the under sides to be left open until a few minutes before totality.

Each station was equipped for the determination of latitude and longitude. At the two Spanish stations time signals were received from the Madrid Observatory over special wires kindly erected by the Spanish government, and at the African station signals were received from the Algiers Observatory. The latitudes were determined by Talcott's method.

Each station was supplied with one of the long-focus cameras mounted horizontally, the one at Porta Coeli having the new lens of 65 feet focal length, the other two stations having lenses of 40 feet focal length. There was also at each station one of the polar axes for carrying one or two cameras for obtaining coronal extension, together with spectroscopic and polariscopic apparatus.

Several parties of sailors, in charge of officers from the naval vessels, made drawings of the corona and shadow-band observations. One of these parties, in charge of the commanding officer of that ship, Captain J. M. Miller, U. S. N., was located on board the U. S. F. S. "Minneapolis," near the central line off the east coast of Spain; another under the charge of Commander G. A. Merriam, U. S. N., was located on board the U. S. S. "Dixie" near Bona, Algeria.

At each station a complete meteorological equipment was set up, and provision was also made for magnetic and photometric observations.

At none of the stations was there any interference from clouds, and the programs were carried out as planned.

The contacts were observed at all the stations, and were noted about twenty seconds ahead of the predicted time.

CORONAL PHOTOGRAPHS

Thirty-six photographs of the corona were taken at the three stations. At Daroca Mr. L. G. Hoxton obtained seven with the 40-foot camera, the exposure times being $\frac{1}{2}^s$, 2^s, 5^s, 45^s, 120^s, 5^s, and snap-shot; Paymaster H. R. Insley, U. S. N., obtained three with the

12-foot camera, of 5^s, 70^s, and 10^s exposure; and Midshipman E. W. Chafee, U. S. N., obtained three with the 36-inch Dallmeyer camera and color-screen, of 5^s, 70^s, and 40^s exposure. The drawing of the corona, Plate IX, was made from a study of the Daroca negatives.

At Porta Coeli Mr. G. H. Peters obtained seven negatives with the 65-foot camera, of 2^s, 3^s, 35^s, 5^s, 15^s, 3^s, and 2^s exposure, and four were obtained by Mr. G. A. Hill, with the 104-inch camera of 5^s, 10^s, 40^s, and 20^s exposure.

At Guelma Mr. W. W. Dinwiddie secured eight negatives with the 40-foot camera, the exposure times being 2^s, 5^s, 13^s, 88^s, 38^s, 7^s, 5^s, and $\frac{1}{4}^s$ ten seconds after the third contact; and Yeoman F. A. Achen four with the 15-foot camera, of 30^s, 55^s, 90^s, and 10^s exposure.

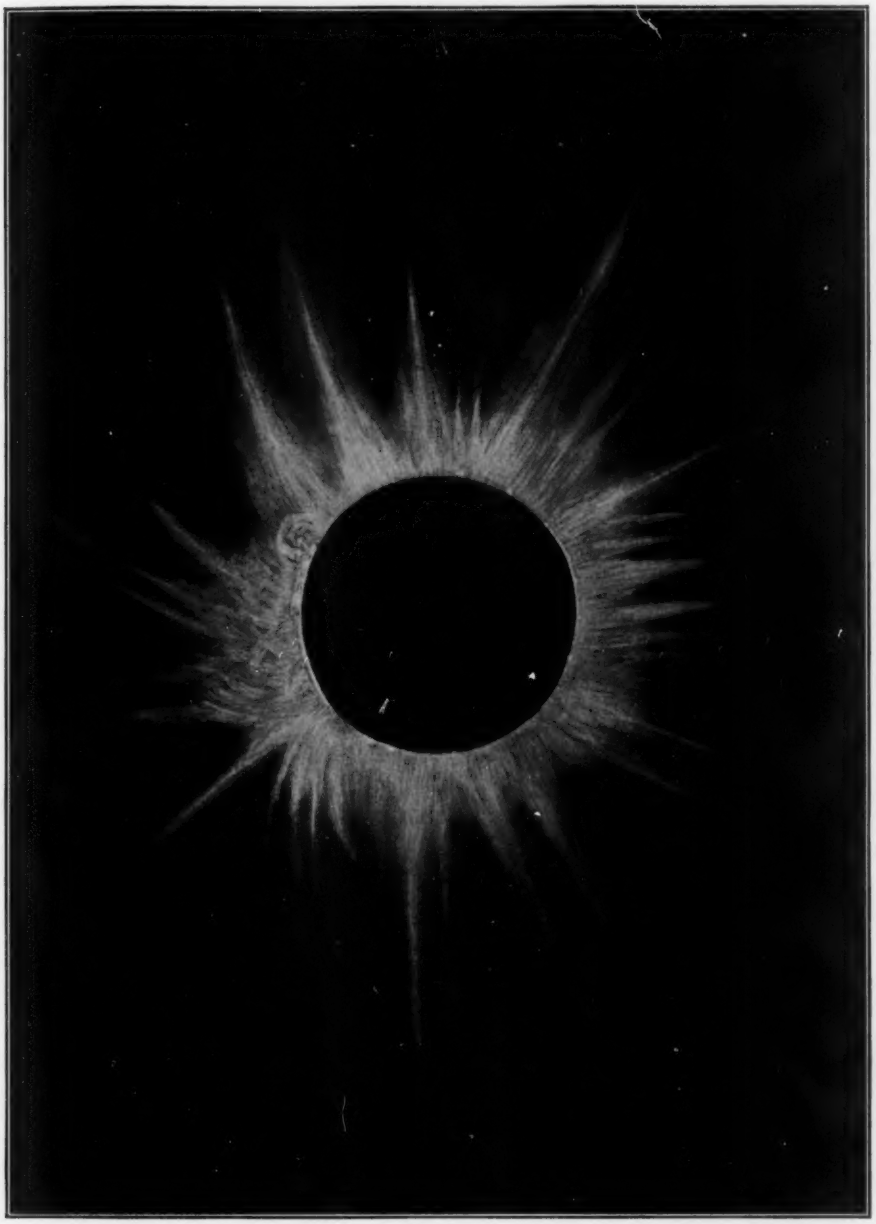
Both the early and late photographs with the long-focus cameras show numerous prominences, and the longer exposures show a great amount of intricate detail in the corona. The shorter-focus cameras show the corona extending two or three diameters from the limb of the Moon. On the last negative with the 40-foot camera at Guelma, taken ten seconds after third contact, the entire ring of the corona is visible, and the prominences on the bright limb are shown in fine detail.

SPECTROSCOPIC OBSERVATIONS

All spectroscopic work at the central Spanish station was in charge of Dr. S. A. Mitchell.

The success attending the work at the eclipses of 1900 and 1901, when gratings were used, was such as to show that splendid results might be obtained at the eclipse of 1905 from these gratings. Accordingly, the spectroscopic program included primarily large-scale photographs of the "flash" spectrum and the coronal spectrum to be obtained in this way. As there was a question as to whether the concave grating or flat grating were the better, it was decided to use both. In addition to the two powerful gratings, a short-focus concave grating was to be used for the purpose of finding the changes in the bright lines of the Sun's spectrum, and, finally, two prismatic spectrographs for finding the intensity of the light of the corona in different parts of the spectrum. Thus five spectrographs were used, three grating and two prismatic. In detail the instruments were as follows:

1. *Parabolic grating.*—This grating was the property of the Rum-



Composite Drawing of the Eclipse at Daroca, Spain

From negatives made with the 40-foot and 12-foot cameras.
Drawn by Capt. H. W. Carpenter, U. S. M. C.

ford Committee, and was kindly loaned by Professor F. A. Saunders, of Syracuse University. It is a 4-inch grating, with 14,438 lines to the inch, and has a focal length of almost exactly 5 feet. The spectrum was exceedingly bright in the first order on one side, and the definition was splendid. At the eclipse it was used without a slit, so that the spectrograph consisted merely of grating and photographic plate. The instrument was placed horizontally, and light was fed to it by means of a "Transit of *Venus*" cœlostat which did not work perfectly. On the eclipse day this instrument was placed in the hands of Ensign A. G. Howe, U. S. N., of the "Minneapolis." Eleven plates were exposed, everything passed off without a hitch, and the developed plates show splendid detail and are exceedingly interesting. On account of the spectrum being brought to a focus on a curve, it was necessary to use celluloid films. These films, $1\frac{1}{4} \times 12$ inches, were of two different kinds, Lumière "Panchromatic C" and Seed "Orthochromatic." The dispersion of this instrument is about the same as the Bruce three-prism spectrograph of the Yerkes Observatory and the Mills spectrograph of the Lick Observatory. The distance from D_3 to H is almost exactly 7 inches, the total length of the spectrum being 9.5 inches, and the definition excellent throughout its whole length. The flash extends from D_3 to λ 3300 and shows a very great number of lines.

The spectrum taken near mid-totality shows some interesting coronal rings. The green coronium ring appears very plainly, and two rings in the extreme ultra violet are just as prominent on the photograph as the green ring. As the plate used has a photographic action which is just as intense in the ultra-violet as in the green, it would seem that the corona is very rich in ultra-violet rays. The following coronal lines are seen at approximately $\lambda\lambda$ 3381, 3388, 3455, 3643, 3984, 4228, 4565, 4618, and the coronium line at λ 5303.

2. *Flat grating.*—This grating belongs to the Naval Observatory, has 15,000 lines to the inch, and a ruled surface $3\frac{1}{2} \times 6$ inches. The lens used with it is a Clark 5-inch visual with a focal length of about 6 feet. This instrument was also placed horizontally, and was fed by a Gaertner cœlostat. The field of the spectrum was sufficiently near a plane to allow glass plates to be used. These plates, $1\frac{1}{2} \times 14$ inches, were also of two different kinds, Lumière "Panchromatic C"

and Cramer "Trichromatic." Twelve exposures altogether were made. This instrument was used on eclipse day by Dr. Mitchell, assisted by two sailors of the "Minneapolis." The results are not quite so good as those obtained with the parabolic grating as the extreme ultra-violet is not in focus. On these plates the distance from D_3 to H is 8 inches. In the flash spectrum lines can be seen beyond the D lines toward the red almost to C. This is the end of the spectrum most desired, and the focus is excellent from F to the extreme of the red. The green coronium ring also appears on the plates taken near mid-totality.

3. *Short-focus concave grating.*—This grating, kindly loaned by Professor S. P. Langley, secretary of the Smithsonian Institution, was used for the purpose of finding the changes in the bright lines just before and just after totality. It has a ruled surface of 4×6 inches, with 3610 lines to the inch, and a radius of curvature of 64 inches. In view of its small dispersion, the spectra were excessively bright. The second and third orders were to be photographed on the same plate, and a number of exposures were to be given in quick succession at second and third contacts, the times of exposures being recorded on the chronograph. At the time of the eclipse, however, the success of this instrument was greatly interfered with by totality beginning about 20 seconds before the calculated time, so that the exposures at second contact, which were to run on both sides of the "flash," were all inside totality; and, in addition to this, the chronograph pen failed to write. However, the plates promise some interesting results upon more careful study.

4. Two prismatic instruments of the same dispersion were used for the purpose of finding the intensity of the corona in different parts of the spectrum. This was to be done by photographing alongside the coronal spectrum comparison spectra of the Sun under ordinary conditions and at different exposures in such a way that photometric measures might be made. These instruments were used with slits, and each consisted of one prism with the necessary collimator and objective.

The four lenses used were kindly loaned by the C. P. Goerz Co., and the prisms and slits were obtained from the Naval Observatory and the Department of Physics of Columbia University. The result-

ing photographs show the coronal spectrum exceedingly weak, so that no photometric measures are possible.

The spectroscopic apparatus used at the station at Porta Coeli, Spain, consisted of a 6-inch concave grating having a radius of curvature of 21½ feet, and ruled with 15,000 lines to the inch, loaned to the expedition by the Johns Hopkins University.

This was arranged to be used with parallel light reflected from one of the mirrors of a cœlostat in the usual manner, the first order spectrum being employed. Two plate-holders were used, each holding three films 2×24 inches, Seed "Orthochromatic." The region of the spectrum covered was from λ 3000 to λ 6000 approximately.

The duration of totality at this station being about 106 seconds, the exposures were arranged as follows, time being counted from the moment of second contact: 1, 0 to 4 seconds; 2, 6 to 20 seconds; 3, 22 to 70 seconds; 4, 86 to 100 seconds; 5, 102 to 106 seconds; 6, exposed for perhaps ½ second as soon after third contact as possible.

From the exposure times it is evident that plates 1 and 5 were intended to get the flash spectrum at second and third contacts; plates 2 and 4 to get the upper chromospheric and inner coronal lines; while plate 3 with the long exposure was intended to get principally the coronal spectrum. Owing to the moderate height of the solar atmosphere covered up by the Moon at mid-totality as seen from this station, it follows that the highest chromospheric lines, such as H and K, etc., would appear to some extent on all the plates.

Professor Littell changed the plates, and Mr. Anderson worked the shutter and determined the time for beginning the first and ending the fifth exposures, by observing the Sun directly through a small objective-grating direct-vision spectroscope. The observation of the time of second contact agreed almost exactly with that given by Commander Hayden, who observed at the 5-inch equatorial, and gave the signals to "begin" and "stop" for the photographic cameras; while the observation of the time of third contact was about two seconds behind that of Commander Hayden, who called "stop" at the count of the 104th second.

The plates were developed the evening of August 30. They show

quite an amount of detail, but the definition in general is not so good as might be wished. This may be ascribed to two causes: imperfect focusing, and vibration of the instrument during exposure.

The flash-spectrum plates both show a great amount of detail; plate 5 showing much more, however, than plate 1, indicating that its exposure was more nearly correct than that of plate 1; the definition on this plate is also very good, so it is hoped to get a great deal from it. Plates 2 and 4 show the higher chromospheric lines well, but do not show any of the coronal rings, and very little if any continuous spectrum. Plate 3 shows the green coronal ring fairly well, and quite a considerable amount of continuous spectrum, but fails to show any of the other coronal rings distinctly enough to allow of measurement. It also shows quite a number of the so-called inner coronal lines. None of the plates shows any lines beyond λ 3300, and possibly nothing beyond λ 3400.

Two of the prominences show a displacement of the calcium and hydrogen lines indicating motion in the line of sight, as it is greater in case of calcium than of hydrogen, and also much greater on plate 2 than on any other.

The spectroscopic work at the African station was in charge of Mr. L. E. Jewell, and the following instruments were employed.

(1) A 6-inch concave grating of 10 feet radius and 15,000 lines to the inch, belonging to the Naval Observatory. This instrument was used as a direct grating and was mounted on the polar axis. Eight exposures were planned for this instrument: $\frac{1}{2}^s$ ten seconds before totality; 3^s beginning at second contact; 30^s, 55^s, 90^s, 10^s, $3^s\pm$ ending at third contact; and $\frac{1}{2}^s$ as soon as possible after the end of totality.

On developing the films it was found that the program as planned and practiced had not been correctly carried out. Due probably to second contact occurring about 20 seconds before the predicted time, the first two exposures were late and the first flash was missed. The longer exposures show the chromospheric lines not perfectly sharp, yet fairly so, and the coronal rings generally excellent. The exposure for the second flash was not ended promptly at third contact, and as a consequence the spectrum of the solar crescent was allowed to come out on it for a short time. It is a fairly good film, however. The first

and last exposures of half a second each show considerable shaking of the instrument, and the others in a less degree.

The green ring shows remarkably well upon three plates, fairly well upon two others, and is suspected upon a sixth.

The ultra-violet rings at λ 3382 and λ 3453 show well upon two films, fairly so upon a third, and are suspected upon one or two others.

Between H and D_3 there are three coronal rings that show with certainty at λ 3987, λ 4231, and λ 5303. In addition, four other rings are suspected in this region, while a number of inner coronal arcs are visible. The ultra-violet rings at λ 3644 and λ 3802 do not show very distinctly.

Probably the most interesting features shown by the films taken with the 6-inch concave grating spectrograph are the details shown by the green coronal ring, and to a less extent by some others. In the green coronal ring there are at least 15 or 20 small streamers or projections, the most remarkable of which is a narrow streamer starting from the Moon's limb at latitude about 35° or 40° south of east, and stretching for about 5 minutes of arc as a slightly in-curved streamer toward the northeast, just crossing the solar equator. This streamer shows with certainty upon five films, and it is thought to be faintly visible in the ultra-violet ring at λ 3382. In the ring at λ 3454 there are some slight defects on the best film where the streamer would show.

There are a number of small projections or short streamers at various latitudes, and the region of the equator on both the east and west sides shows very bright patches, particularly the west sides.

Another striking feature of the green coronal ring showing plainly upon the second, third and fourth films, but not so well upon the fifth and sixth, is a nearly radial dark streamer with a strong bright streamer to the south of it and a small bright streamer to the north of it. The dark streamer starts from the Moon's limb at about latitude 55° or 60° south on the Sun's east limb. The photographs with the 15-foot camera show a dark radial streamer or rift with bright streamers each side of it at the same place, and they are without much doubt identical. The narrow curved streamer is apparently not to be seen in the coronal photographs, although they have not been compared with short exposures showing faint detail in the inner corona. The dark radial streamer shows upon all the photographs of the corona

which have been examined, but the spectrograms show it much the best, and most extensively upon the second and third exposures, and hardly at all upon the sixth exposure. An examination of the four films indicates that the phenomenon was a comparatively short-lived one. It can be seen in the coronal ring at λ 3382 also. The coronal ring in the green shows no connection whatever with prominences, and only with part of the streaks of continuous spectrum, and the evidence at hand indicates that there is only a partial correspondence with the inner corona as shown upon photographs.

Next in interest is the ultra-violet chromospheric spectrum. Some lines are visible between λ 3000 and λ 3100, and a great many from that on toward the visible spectrum. Prominent among the lines in the extreme ultra-violet part of the spectrum are those due to titanium, chromium, manganese, and scandium. Among the more interesting and stronger lines in the extreme ultra-violet are the chromium lines at λλ 3132.2, 3125.1, 3120.5, and 3118.8.

Upon the best film taken at Guelma the farthest lines which can be detected are manganese lines at λ 3035.5 and λ 3038, which are, however, so faint as to be more or less uncertain. The helium lines are prominent throughout the spectrum.

(2) A 5-inch concave grating of 12 feet radius and 10,000 lines to the inch, mounted horizontally and fed with light from the mirror of a cœlostat. This grating was used with a slit, and as it was intended particularly for coronal radiations, it was thought best instead of a single radial slit to use a multiple slit composed of four slits so placed as to cross the corona at 12½° on each side of the equator, one pair on the west and the other on the east limb of the Sun. This was done in order to stand a better chance of having at least one of the slits cross those parts of the corona where the material producing the coronal rings happened to be brightest. The light from the cœlostat mirror was condensed upon the slit by a 6-inch parabolic reflector of 15 feet radius, and a similar reflector was used to render the light parallel after passing through the slit and before falling on the grating.

The development of the exposures made with the multiple-slit spectrograph showed that, in spite of the precautions taken in diaphragming, the films received light other than that diffracted from the grating, so that the development could not be carried far enough to

show all that the films would have shown otherwise; also the grating was not bright enough to give sufficient light to show the coronal lines with certainty. Nevertheless, one film shows considerable detail, about 16 hydrogen lines appearing with one of the slits, and the hydrogen line near H exhibiting the separation from that line very sharply. There is also an indication of motion in the line of sight in both directions with some of the lines. The other slits were not over as bright regions of the chromosphere or prominences, do not show so much, and do not show any line-of-sight motion. The lines showing motion are due to prominences on the east limb. The coronal spectrum appears as continuous spectrum, the grating not being bright enough to show distinct coronal lines with certainty.

The lines on the films are quite sharp, and since they were made with a slit and the position of the lines is not affected by the distribution of matter in the chromosphere, they should give very good determinations of wave-length, especially for the ultra-violet hydrogen lines.

There were three exposures made with this spectrograph:

First exposure from 5^s after totality to 30^s after; duration 25^s.
Second exposure from 35^s after totality to 3^m after; duration 2^m 25^s.
Third exposure from 3^m 5^s after totality to 3^m 30^s after; duration 25^s.

The first film gives the most in the way of results; the second one shows the coronal spectrum to be for much the greater part continuous; and the third film was a defective one, having spoiled from some cause. However, some lines can be seen upon it.

(3) A 4-inch concave grating of 10 feet radius and 1000 lines to the inch. This instrument was used direct with a Cramer "Trichromatic" plate in a sliding plate-holder, and was mounted on the polar axis. The results with this instrument were unsatisfactory.

The 6-inch concave grating used at Porta Coeli, the 5-inch and 4-inch grating, used at Guelma, and the 6-inch parabolic reflectors were secured through the kindness of Professor J. S. Ames, of the Johns Hopkins University.

In the visual observations made with the direct-vision spectroscope, the yellow helium line D_3 was particularly prominent. Particular attention was paid to the yellow helium line, the green-blue hydrogen F, the red hydrogen line C, and the green coronal line.

Much to the observer's surprise, the yellow helium line was very nearly as strong as the two hydrogen lines, and remained visible throughout the total phase of the eclipse. It was nearly as prominent throughout as either of the hydrogen lines, none of them, however, forming a complete ring, but being visible in patches due to prominences. The lines D_3 and F ($H\beta$) show on the spectrograms taken at mid-eclipse, but the yellow helium line, because of the comparative insensitiveness of the film to the yellow, is not nearly so prominent relatively to F as it was to the eye.

The green coronal line was carefully observed, but the spectrograms show as much as was visible to the eye, except that the extent or height about the Moon's limb was somewhat greater as seen with the spectroscope than is shown upon the spectrograms. The very bright patches connected with the green coronal ring and the streaks of continuous spectrum shown on the spectrograms were distinctly visible in the spectroscope.

The Fraunhofer crescents as seen with the spectroscope became distinct about seven minutes before the second contact, and D_3 and the hydrogen lines became bright lines about one and a half or two minutes before. By that time the dark bands through the spectrum in the direction of its length, due to irregularities of the Moon's limb, had begun to cut up the Fraunhofer crescents very much, and it became evident that second contact would occur earlier than had been calculated. After second contact the smaller bright lines faded rapidly, those of medium length more gradually, and the green magnesium lines lasted faintly until near mid-totality. The green coronal ring attracted attention as soon as totality began.

POLARISCOPIC OBSERVATIONS

Polariscopic work was carried on at only one of the stations, at Guelma, Africa, and was in charge of Dr. N. E. Gilbert, of Dartmouth College. The principal object of these observations was to determine the amount and distribution of polarized light in the corona. An attempt was also made to verify the observations of Mr. and Mrs. Newall[1] to the effect that an abrupt change takes place in the direcrection of polarization of sky-light at the beginning and end of totality,

[1] *Proc. R. S.*, **67**, s. 365, 1901.

but it became necessary to intrust these observations to an assistant from the men of the "Dixie," and the results were unsatisfactory.

For the observations upon the corona two instruments gave satisfactory results.

a) A "*photo-polarigraph.*"—This consisted of a photographic camera with a Nicol prism placed before the objective. The Nicol used was an exceptionally fine one with an aperature of 3.8cm. This was mounted, free to rotate, upon the front of the camera base, and a handle attached to the case was provided with stops so that the Nicol could be set quickly, even in the dark. The objective, placed immediately behind the Nicol, was an achromatic lens 8 cm in diameter and 85 cm in focal length. The plates used were 4×5 inch Seed "Gilt Edge." The instrument was mounted upon the large polar axis.

Two exposures were made, one of 10 seconds and one of 30 seconds in each of three positions of the Nicol separated by 45°. All of the six negatives show a dense ring of light about the Moon's disk. This shades off uniformly in all directions at first, then more rapidly in the direction parallel to the principal plane of the Nicol. In the direction perpendicular to the principal plane streamers can occasionally be traced nearly two diameters from the disk.

Comparing these negatives, certain points stand out sharply. Inside of four or five minutes of arc the intensity shades off uniformly on all sides of the Moon's limb. No sign of polarization is visible. Beyond this limit the proportion of polarized light increases rapidly. In the direction perpendicular to the principal plane of the Nicol, i. e., in the direction in which the Nicol allows radially polarized light to enter, the depth of continuous corona varies from12′ to 17′, with an average of 13′; while in the direction parallel to the principal plane the depth varies from 8′ to 10′, with an average of 9′.5, a difference of 3′.5 depending upon the Nicol. This difference serves to give the image of the continuous corona a distincly elliptical form in every negative. If we average separately the short and the long exposures, we find, for the direction perpendicular to the principal plane, 12′.3 and 14′ respectively, and for the direction parallel to the principal plane 9′.3 and 9′.7 respectively. Increasing the exposure threefold has added 13.1 per cent. to the extent in the former direction, and 4.12 per cent. in the latter direction. Too much weight should not be placed upon the

exactness of these figures, but it is safe to say that practically all of the light beyond 10′ of arc in the continuous ring is polarized radially.

The amount of light in the streamers which is not polarized radially is small. On account of the great irregularity in the position, extent, and brightness of the streamers averages would mean but little. In the following table have been collected the figures representing the extent to which the most prominent streamer in each of four directions is visible on the negatives:

No. of Negative	Exposure	Transmitted Light Polarized	N.	S.	E.	W.	Extent of Inner Corona	
							N. and S.	E. and W.
1	10^s	N.–S.	28′	44′	12′	12′	12′	10′
3	10^s	E.–W.	12′	12′	28′	32′	10′	12′
5	30^s	N.–S.	32′	50′	15′	12′	13′	10′
6	30^s	E.–W.	24′	18′	28′	40′	10′	12′

Negatives No. 2 and No. 4 are omitted because no plates were taken with which they can be compared directly. Averaging the figures for these four streamers, we have for extension beyond continuous corona:

Extension on side of transmitted light . . . . . 23′
Extension on side of "extinguished" light . . . . 4′.6

These figures indicate that practically all the light in the streamers is polarized radially. For increase in length due to increasing threefold the time of exposure:

Increase on side of transmitted light . . . . 4′.5
Increase on side of "extinguished" light . . . . 5′.2

This increase is practically the same in the two directions. The exact amounts are difficult to measure on account of fogging of the background, in the long exposures, by sky-light.

The value of observations such as these for the study of polarization depends wholly upon the possibility of making direct comparisons between negatives taken under conditions as nearly as possible identical. Two negatives taken in succession lose something in value on this account. Double image prisms as fine as the Nicol used in the polarigraph at Guelma are extremely rare, but two images taken simultaneously with the same instrument would allow more minute comparison of details, and so would possess advantages which would partly compensate for the defects of a poorer crystal.

b) *A "spectro-polarigraph."*—This consisted of an ordinary 45-degree prism spectroscope with a photographic attachment, a Nicol prism being placed immediately behind the slit. This was also mounted upon the polar axis. The slit, $\frac{1}{10}$ mm wide, was placed across the center of the Moon's disk, parallel to the Sun's equator. Two exposures, on the same plate, were made, the length of each being $1^m\ 25^s$. The Nicol was rotated 90° between exposures.

No 1. Principal plane of Nicol perpendicular to slit. Light polarized radially in equatorial regions of the corona transmitted.

On the east side of the Moon's limb are some nine bright lines due to the prominence which covered the slit at this point. These are much overexposed. They can be identified roughly by superposing the plate upon a reference plate taken from sky-light before the eclipse. The H and K lines are very strong, and the others appear to coincide, as expected, with prominent hydrogen and calcium lines. No trace of these lines appear on the west limb. It was hoped that traces of dark Fraunhofer lines might be found on this plate, but none appears.

The continuous spectrum covers the region from about λ 5200 to λ 3800. It is very strong, being overexposed, and extends over about a half diameter on either side of the Moon's limb. The contrast with the companion negative on the same plate is most striking.

No. 2. Principal plane of Nicol parallel to slit. Light polarized radially not transmitted.

Only faint traces of two bright lines, probably the H and K lines so strong in No. 1, are visible. The absence of these lines is probably due to the fact that the prominence was covered before this exposure was made. No Fraunhofer lines were expected, as all light except that from the inner corona was excluded by the Nicol.

The length of the continuous spectrum is practically the same as in No. 1, but it is only 6′ wide, and much weaker near the outer edges. This plate verifies fully the results derived from the photo-polarigraph plates; i. e., there is no appreciable amount of polarized light inside of 4′ or 5′, but beyond 6′ or 7′ practically all the light is polarized radially.

Conclusions.—The six plates obtained with the photo-polarigraph and the two with the spectro-polarigraph are entirely consistent and satisfactory. They supplement and confirm completely the results

obtained in recent eclipses. The quantitative results are quite definite. Inside of five minutes of arc there is practically no light polarized radially. This, then, is not reflected light, but the source is self-luminous matter, very largely solid, as is shown by the strong continuous spectrum. Between five and ten minutes of arc the amount of polarized light increases very rapidly, showing that the light is reflected sunlight. The presence of the dark Fraunhofer lines in the outer corona has been so often demonstrated that the absence of these lines on my plates proves nothing against these conclusions. An instrument with better definition would doubtless have obtained them.

METEOROLOGICAL OBSERVATIONS

All the meteorological work connected with the expedition was in charge of Professor F. H. Bigelow, of the U. S. Weather Bureau.

Complete records of the pressure, temperature, relative humidity, wind, direction and velocity, amount and kind of clouds, were secured for the astronomical stations at Daroca, August 5-31; Porta Coeli, August 3-31; Guelma, August 4-31; and for the auxiliary meteorological stations at Zaragoza, August 14-31; Guadalajara, August 14-31; Tortosa, August 23-31; Castellon partial records during August, and Bona throughout the month; also on the ocean voyages in both directions. The weather during August was very favorable till August 29, when a rain storm covered Spain, and disturbed the normal conditions which it was hoped would prevail for two days longer. On August 30 there was partial cloudiness, the eclipse being wholly or partly obscured at Castellon, Tortosa, and Zaragoza, but seen clearly at Porta Coeli, Daroca, and Guadalăjara; also at Guelma and Bona, Africa.

The effect of the shadow upon normal conditions of the atmosphere cannot be studied as fully as desired on account of this disturbance in Spain. On the day of the eclipse especially complete records were made at all the stations by the co-operation of the Spanish officials in charge of the observatories at Tortosa, Zaragoza, Guadalajara, and Castellon. Generally the pressure was undisturbed, the temperature fell about 8° F. at Daroca, and Porta Coeli, and less at the other stations, the relative humidity increased, the cloudiness increased, but no effect on the wind was noted to be of significance.

Long series of observations were made on the atmospheric electricity, including the electric potential gradient, the number and velocity, of the ions and the general electrical conductivity. The polarization was observed for several days at Daroca, and the radiation was measured at Guelma. On the ocean voyage were secured seven kite ascensions on the outward trip and one on the homeward trip. The electrical conditions were observed continuously on the homeward voyage; also some radiation and polarization readings were made on the ocean. It has been shown that good results can be obtained with the actinometer and the polarimeter at sea in moderate weather.

MAGNETIC WORK

Magnetometers and dip circles were established at Porta Coeli, Spain, and at Guelma, Algeria, and series of observations were made for several days preceding and on the day of the eclipse, the latter, especially, involving very delicate and laborious work. From 10 A. M. to 4 P. M. on August 30 eye-readings of the declination needle were made once a minute, with frequent readings of the thermometer, and during totality readings were made every fifteen seconds. The two midshipmen detailed for this arduous duty were Mr. N. H. Wright at Guelma, and Mr. J. H. Lofland at Porta Coeli, and their results will be taken up for study as soon as practicable.

U. S. Naval Observatory,
Washington, D. C.,
January 30, 1906.

A GREAT PHOTOGRAPHIC NEBULA NEAR π AND δ *SCORPII*

By E. E. BARNARD

Through the courtesy of Professor Hale and the generosity of Mr. John D. Hooker, of Los Angeles, I spent the past spring and summer in photographic work at the Solar Observatory of the Carnegie Institution on Mount Wilson, California, at an altitude of 6000 feet. Mr. Hooker's generous grant made it possible to transport the Bruce Photographic Telescope of the Yerkes Observatory to Mount Wilson, where it was installed from February until September, 1905. It is hoped that the results may later be published in full, with reproductions of the principal photographs. At this time I wish to call attention to an especial region in *Scorpio.*

The main object of the work at Mount Wilson was to secure the best possible photographs of the Milky Way as far south as the latitude would permit. But little time was available for independent investigations in other parts of the sky, though the conditions for such work were often superb.

A few exposures were made, however, at various points in a search for diffused nebulosities. The extraordinary nebulosities in *Scorpio* and *Ophiuchus* which I found by photography in 1894—those of ρ *Ophiuchi*, ν *Scorpii*, etc.—suggested the immediate region of the upper part of the Scorpion as a suitable hunting-ground. Trial plates were exposed on ρ *Scorpii*, and π *Scorpii*, and elsewhere. The photographs of the region of π showed a very remarkable, large, straggling nebula extending from π to δ *Scorpii*, with branches involving several other naked-eye stars near.

With the exception of the great curved nebula in *Orion* and some of the exterior nebulosities of the *Pleiades*, this nebula is quite exceptional in its extent, and in the peculiarities of its various branches. A simple description of it would be inadequate to give a fair conception of these features.

It is difficult to properly reproduce the photograph because of the

PLATE X

N

E

W

GREAT PHOTOGRAPHIC NEBULA NEAR π AND δ *SCORPII*

1905 April 29 and 30. Exposure $8^h\,45^m$ Scale: $1^\circ = 23.3$mm.

faintness of some of the extensions of the nebula. Enough can be shown, however, to give some idea of its general structure (Plate X).

The plate from which the reproduction was made was exposed on two nights. These were 1905, April 29, $18^h\ 52^m$ to $23^h\ 12^m$, and April 30, $18^h\ 32^m$ to $22^h 52^m$, G. M. T. The photograph was therefore given a total exposure of $8^h\ 40^m$. The conditions during the exposures were not especially good. The sky was whitish during the first exposure, with some mist. On the second night the sky hazed up and stopped the exposure. The position was far south and over the valley and the ocean. Had I been more fortunate in the selection of the nights for this long exposure, I am confident that the extent of the nebula would have been much greater, for the plate shows but little more nebulosity than is shown on two other plates with half the exposure time. Had this photograph been made on some of the superb nights that came later on, I think the extensions of the nebula might have been carried beyond the dimensions of the plate, for besides the portions that are clearly shown, vague suggestions of it can be traced to much greater distances.

The brightest portion of the nebula lies about $\frac{1}{2}^\circ$ south of π *Scorpii.* It is a rather long, wavy mass, inclined some 40° to the southwest. This portion has a narrow extension for nearly a degree to the east, and a curved arm extends upward to π. A larger diffused mass, well defined at its east side, extends from the southwest of π north to the 6.7 mag. star *Cord. DM.*—24°.12365. This portion covers a wide area to the south and west, where it fades insensibly into the sky. A diffused branch extends to and beyond the 5.3 mag. star *Cord. DM.* —25°.11131. The 5.5 mag. star *Cord. DM.*—24°.12352 has a brightish mass extending to the southwest some 15′ or 20′. From this last star the nebulosity curves northward and east to the 5.8 mag. star *Cord. DM.*—24°.12354, and thence in a straggling manner northeast to δ *Scorpii*, and for a degree beyond that star. From the stream running to δ an irregular broader mass runs east for a degree or more. The full extent of the nebula north and south is about $4\frac{1}{2}^\circ$ or 5°. There is a diffusion of the nebulosity for some distance to the east of δ.

The 5.3 mag. star, 13 *Scorpii*, is strongly nebulous on this photograph (and on two other plates), but falls outside the limits of the

present reproduction. This star is *Cord. DM.*—27°10841, and its place for 1875.0 is

$$\alpha = 16^h\ 4^m\ 36^s.6\ ,\quad \delta = -27°\ 35'.7\ .$$

There are also two trails (one for each night) of the same asteroid on this plate in about $\alpha = 15^h\ 42^m \pm$, $\delta = -23°.6 \pm$. These trails will be found 61.5 mm from the upper edge and 27 mm and 31 mm, respectively, from the right-hand edge of the plate.

A striking fact in connection with this nebula is that all the larger stars connected with it, whose spectra have been observed, are of the *Orion* type. Professor Frost informs me that the *Orion* stars, from the peculiarities of their spectra, are thought to be in a primitive condition, and are the most likely—as is shown also by photography—to be associated with nebulosities, while the converse seems to hold for stars of the more advanced types of spectra.

Though some of the stars on this plate are doubtless only apparently connected with the nebula, there seems to be no doubt that others are really in the nebula.

In thinking over this object recently, I recalled the fact that in photographs of *ν Scorpii*, which I made at the Lick Observatory in 1895, there were traces of nebulosity about *π Scorpii* which I did not have the opportunity to investigate further at the time. An examination of these plates shows that the brighter mass close to and south of *π* is visible. The image of that star is in the region of bad spherical aberration. The extended branches are too far west to be on the plates.

The present photograph was made with the 10-inch Brashear lens of the Bruce photographic doublet.

Such nebulæ as this one, and others of similar branching, straggling appearance, rather tend to make one doubt the generally accepted form of the nebular theory. Indeed, this theory seems to have been built mainly upon the the visual appearance of the nebulæ when seen in very inferior telescopes. It seems to me doubtful if the nebular theory would have been constructed at all if at that time our present knowledge of the appearance of the nebulæ, as shown by photography, had been available. It has always seemed to me that the

nebular theory accounts for the existence of the stars in a very strained manner, and that it has very little to commend it.

While there are some of the nebulæ (I do not speak now of the spiral nebulæ) that seem to agree in appearance with the theory, there is a much larger percentage that seem to be directly opposed to it. It does not appear necessary that the association of a star and a nebula proves that the star was formed from the nebula.

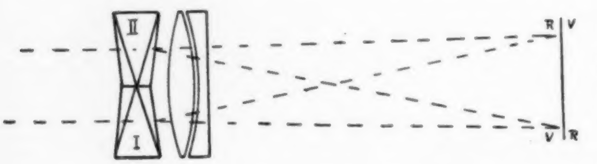
YERKES OBSERVATORY,
February 6, 1906.

A PROPOSED METHOD FOR THE DETERMINATION OF RADIAL VELOCITIES OF STARS

By GEORGE C. COMSTOCK

The following discussion presents in somewhat greater detail the substance of a communication made by the writer to the New York meeting of the Astronomical and Astrophysical Society of America, held December 28-30, 1905. It deals with the problem of determining differentially the radial velocities of many stars by comparison of their spectra obtained with an objective-prism, with the spectrum of a star of known velocity simultaneously impressed upon the same photographic plate.

In the accompanying figure let I represent a direct-vision prism placed in front of one-half of an objective, and let the broken line passing through I represent a pencil of light coming from the standard reference star, *S*, and producing a spectrum, *RV*, upon a photographic plate placed in the focal plane of the objective. Let II represent a similar prism placed in front of the other half of the objective, with its refracting edge turned in the opposite direction, and producing upon the plate a spectrum, *VR*, of the same source, *S*. The two spectra of *S* thus produced will be superposed and crossed, the violet end of one falling upon the red end of the other, and by a suitable construction of the prism any assigned part of one spectrum may be made to coincide with the corresponding part of the other. Let α, β, γ be any three lines in the spectrum of S, preferably so chosen that the wave-length of β is approximately equal to the mean of the other two wave-lengths, and let λ', λ'', λ''' represent these wave-lengths. Denote by $\alpha_{\rm I}$, $\gamma_{\rm II}$, etc., the distance from an arbitrarily assumed origin to the image of α, γ, etc., produced on the plate by the prism marked I or II in the figure, this distance being measured parallel to the length of the spectrum. It is obvious that these distances will depend upon a



considerable number of determining factors, e. g., the construction and adjustment of the prisms, I and II; the wave length, λ, corresponding to the line in question; and other quantities which, collectively, we may represent by the symbol C. We represent this dependence by the equations,

$$\begin{aligned}\beta_{\mathrm{I}} &= \phi\,(\mathrm{I},\ C, \lambda'') \\ \beta_{\mathrm{II}} &= \phi\,(\mathrm{II}, C, \lambda'')\end{aligned} \qquad (1)$$

and denoting by ψ a new function produced by subtraction of the ϕ's we obtain,

$$\beta_{\mathrm{II}}-\beta_{\mathrm{I}}=\psi\,(\mathrm{I},\mathrm{II}, C, \lambda'')=b\ . \qquad (2)$$

It is obvious that the symbol b defined by this equation represents the linear distance on the plate between the two images of the line β. If we now consider another object, in the spectrum of which the same line β is found, we may write for it

$$\beta'_{\mathrm{II}}-\beta'_{\mathrm{I}}=\psi\,(\mathrm{I},\mathrm{II}, C, \lambda''_1)=b'\ . \qquad (3)$$

If the second object possesses a radial velocity sensibly different from that of the first, the wave-lengths λ'' and λ''_1 will differ slightly, and putting $\lambda''_1=\lambda''+(\lambda''_1-\lambda'')$,

$$b'=\psi(\mathrm{I},\mathrm{II}, C, \lambda'')+\psi'\cdot(\lambda''_1-\lambda'')\ , \qquad (4)$$

where

$$\psi'=\frac{d}{d\lambda}\psi\,(\mathrm{I},\mathrm{II}, C, \lambda'')\ . \qquad (5)$$

Subtracting Eq. (2) from Eq. (4) we obtain

$$b'-b=\psi'\cdot(\lambda''_1-\lambda'')\ . \qquad (6)$$

To determine, numerically, the function ψ' we write Eq. (2) for the a and γ lines in the spectrum of S, as follows:

$$\begin{aligned}a_{\mathrm{II}}-a_{\mathrm{I}}=a&=\psi\,(\mathrm{I},\mathrm{II}, C, \lambda'')+\psi'\cdot(\lambda'-\lambda'')+\tfrac{1}{2}\psi''\cdot(\lambda'-\lambda'')^2+\text{etc.}\\ \gamma_{\mathrm{II}}-\gamma_{\mathrm{I}}=c&=\psi\,(\mathrm{I},\mathrm{II}, C, \lambda'')+\psi'\cdot(\lambda'''-\lambda'')+\tfrac{1}{2}\psi''\cdot(\lambda'''-\lambda'')^2+\text{etc.}\end{aligned} \qquad (7)$$

where a and c are quantities analogous to b, and find, when the intervals of the λ's are sufficiently small and approximately equal,

$$a-c=\psi'\cdot(\lambda'-\lambda''')\ , \qquad (8)$$

which determines ψ' in terms of measurable quantitites when the wave-lengths of a and γ in the source S are known. It may be noted that a constant error in the values of these wave-lengths, or a small error in the assumed radial velocity, does not sensibly affect the determination of ψ'.

We now have from Equations (6) and (8),

$$\lambda_1'' - \lambda'' = \frac{(b'-b)(\lambda'-\lambda''')}{a-c} , \tag{9}$$

and representing by $v_1 - v$ the difference in the radial velocities of the two stars, by V the velocity of propagation of light, and introducing the Doppler principle,

$$\frac{\Delta v}{V} = \frac{\Delta \lambda}{\lambda} ,$$

we obtain,

$$v_1 = v + \frac{V(\lambda'-\lambda''')}{a-c} \cdot \frac{b'-b}{\lambda''} . \tag{10}$$

Representing by C the coefficient of the last term in Eq. (10),

$$C = \frac{V(\lambda'-\lambda''')}{a-c} , \tag{11}$$

we note that this coefficient may be regarded as a factor characteristic of the plate and standard star, and that its value may be derived from any pair of lines in the spectrum of any star chosen as the standard. When so derived it relates to the point of the spectrum midway between the lines in question, and it is obvious that if a number of values of C are obtained, distributed throughout the spectrum, there may be found from these by interpolation the value required for use in connection with any particular line β that may be measured in the spectrum of another star. Equations (11) and (10), written in the form,

$$v_1 = v + C \cdot \frac{b'-b}{\lambda''} , \tag{12}$$

therefore constitute a solution of the problem, but the adequacy of this solution remains to be determined by experience. It may prove necessary to deal more rigorously with the determination of the function ψ'; and, on the other hand, it may prove possible to obtain such stability of instrumental adjustment as to warrant a calibration of the apparatus, a constant curve for the determination of ψ', that may be employed at several successive settings, thus obviating the necessity of a standard star on every plate. It lies beyond the scope of the present paper to develop considerations of this kind or to discuss the numerous practical details and possible difficulties attending the application of the method here proposed. Some of these, such as the

effect upon the spectra produced by temperature changes, the advantage of substituting a doublet in place of the single objective shown in the figure, etc., have already been suggested by others. The author hopes to deal experimentally with all such considerations affecting the observational side of the method. In case these difficulties shall prove not insurmountable, the advantages of the method are obvious, e. g., the possibility of dealing with many stars at a single exposure and of extending determinations of radial velocity to stars much fainter than any hitherto investigated.

WASHBURN OBSERVATORY,
MADISON, WIS.,
January, 1906.

MINOR CONTRIBUTIONS AND NOTES

ON THE SPECTRUM OF THE SPONTANEOUS LUMINOUS RADIATION OF RADIUM. PART IV: EXTENSION OF THE GLOW[1]

In our second paper[2] we suggest "whether the β-rays, which are analogous to the cathode corpuscles, may not be mainly operative in exciting the radium glow. On this surmise it would be reasonable to expect some little extension of the glow outside the limit of the solid radium itself. We are unable to detect any halo of luminosity outside the limit of the solid radium bromide; the glow appears to end with sudden abruptness at the boundary surface of the radium." We omitted to state that this conclusion was arrrived at by eye observations. The radium was observed in the dark with a lens, and with a low-power microscope.

The earlier photographs of the spectrum of the glow were taken, for the purpose of comparison spectra, with the height of the slit reduced by shutters so as to be within the width of the exposed radium bromide, and, therefore, these photographs would not show whether the bright bands of nitrogen extend into the air beyond the radium. Subsequently photographs were taken with the whole height of the slit, and on these we find that all the bands of nitrogen do extend to some little distance outside the radium salt. Our attention at the time being directed to other phenomena of the glow, we did not examine the photographs to see if the nitrogen bands extended beyond the radium.

In a paper, dated August 22, 1905, F. Himstedt and G. Meyer[3] state that in the photographs of the spectrum of $RaBr_2$, the four nitrogen bands, $\lambda\lambda$3577, 3371, about 3300, and 3159, extend beyond the radium salt, while the other less refrangible bands are not traceable outside the radium. In our photographs all the nitrogen bands project beyond the radium salt; the relative distance to which the extension can be detected in the case of each band being, as might be expected, in proportion to the strength of the impression of that band upon the photographic plate.

[1] From advance proofs of a paper communicated to the Royal Society, December 12, 1905.

[2] *Proc. R. S.*, **72**, 410, 1903; *Astrophysical Journal*, **18**, 390, 1903.

[3] *Ber. d. Nat. Gesells. Freiburg*, **16**, 13–17, 1905.

B. Walter and R. Pohl, in a paper dated September 1905,[1] give an account of experiments made with the help of screens, which show that for a distance of up to about 2 cm, the air surrounding radium bromide has an action on a photographic plate.

On re-examining an early photograph, taken in 1903 for another purpose which is described in our second paper,[2] in which the $RaBr_2$ was enclosed in a very narrow tube of thin glass, we find that the bands of nitrogen, which are strong within the tube, show no trace of extension on the plate beyond the tube. The exposure of this plate was seven days.

This experiment, which we have repeated recently with an exposure of fourteen days, shows that the luminosity of nitrogen in the near neighborhood of radium bromide is not due to the cathode-like β-radiation, for this passes freely through glass.

Two explanations may be suggested: first, that the active cause is the α-rays;[3] or, secondly, that the nitrogen molecules which encounter those molecules of the radium which are undergoing active changes are broken up into ions, which are projected outward, and give rise to the glow of luminous nitrogen[4]

SIR WILLIAM AND LADY HUGGINS.

OBSERVATIONS MADE WITH SELENIUM CELLS DURING THE TOTAL SOLAR ECLIPSE OF AUGUST 30, 1905[5]

During the total solar eclipse of August 30, 1905, a series of observations was made with selenium cells at the Observatory of the Ebro, near Tortosa, Spain, for the double purpose of determining by their means the variation of the quantity of the Sun's light, and of recording the exact instants of the beginning and ending of totality.

I. THE VARIATION OF THE QUANTITY OF THE SUN'S LIGHT

The electric conductivity of selenium is known to be affected by the light of the Sun, especially by its red rays: yellow and green rays have less influ-

[1] *Ann. der Phys.*, **18**, 406, 1905. [2] *Proc. R. S.*, **72**, 412, 1903.

[3] B. Walter, July 1905, showed by means of absorption screens that the radiation from radio-tellurium can produce the ultra-violet light of nitrogen. *Ann. der Phys.*, **17**, 367.

[4] The experiments described in our last paper showed that probably the β-rays are not the operative cause of the nitrogen glow. *Proc. R. S.*, **76**, 488, 1905; *Astrophysical Journal*, **22**, 204, 1905.

[5] "Zwei Beobachtungen mittels Selenzellen bei der totalen Sonnenfinsterniss am 30. August 1905," by Th. Wulf and J. D. Lucas, S. J., *Physikalische Zeitschrift*, **6**, 838-847, 1905. Translated, condensed and diagrams redrawn by William F. Rigge, S. J., Creighton University, Omaha, Neb.

ence upon it, while violet and ultra-violet, as well as infra-red, have none whatever. As it is pretty safe to assume that all the spectral colors of the Sun are diminished equally during an eclipse, the quantity of solar light is directly proportional to the electrical conductivity of selenium. This assumption, however, will not hold for the light received during the early morning and late evening hours, since the red rays are then present in greater proportion. While a selenium eye would therefore see the twilight too strongly, it is true that in general its power of perception is the same as that of the human eye, since both are sensitive to nearly the same colors. For this reason the perception of our visual sense may properly be supplemented and corrected by measurements made with selenium.

Apparatus.—The selenium cell used in these investigations was a flat one made by Ruhmer in Berlin six months ago. It was fastened upon the mirror of a heliostat, which was made to face the Sun directly.

A battery of five storage cells was placed in series with the selenium and a D'Arsonval galvanometer made by Siemens and Halske. The latter had a resistance of 84 ohms and was in shunt with 0.4 ohm. The resistance of the selenium cell varied between 2000 and 30,000 ohms. The current was therefore directly proportional to the conductivity of the selenium. Replacing the selenium cell by a known resistance determined its absolute conductivity and also the accidental changes in the battery.

Method of observing.—The observations were carried on during the entire day of the eclipse, from an hour before sunrise until after sunset. They were made generally at intervals of half an hour, but at much shorter intervals at the times of the Sun's rising and setting and during the partial phase of the eclipse, while during the total phase they were carried on continuously.

The measurements were made in this way. First the battery was tested by inserting a resistance-box of 2221 ohms in place of the selenium. This regular test was found to be necessary during the forenoon because the battery was used also for other purposes at the Observatory. Later on, however, all other circuits were interrupted and the battery proved to be very constant, especially during the time of the eclipse.

After this test of the battery, the resistance of the unilluminated selenium cell was measured, then the cell was exposed to the light for a minute and its resistance measured again, and finally the battery was again examined.

The selenium cell was covered up immediately after each exposure except just before totality, when a large number of measurements of its conductivity was made in rapid succession.

Fig. 1 is a graphic representation of the results. The numbers denote

the hours of Greenwich time, B and E the moments of first and last contact respectively, and T the period of totality. The upper curve shows the conductivity of the illuminated or bright selenium, and the lower that of the unilluminated or dark. The diagram shows that the periods of rest allowed the selenium were not at all sufficient to completely restore its "dark resistance." It is interesting, however, to notice that as the brightness of the midday Sun is being diminished by the eclipse $(B-T)$, the conductivity of the dark selenium is also on the decrease. The difference of the ordinates of the two curves therefore gives a more accurate picture of the actual intensity of the light at the time.

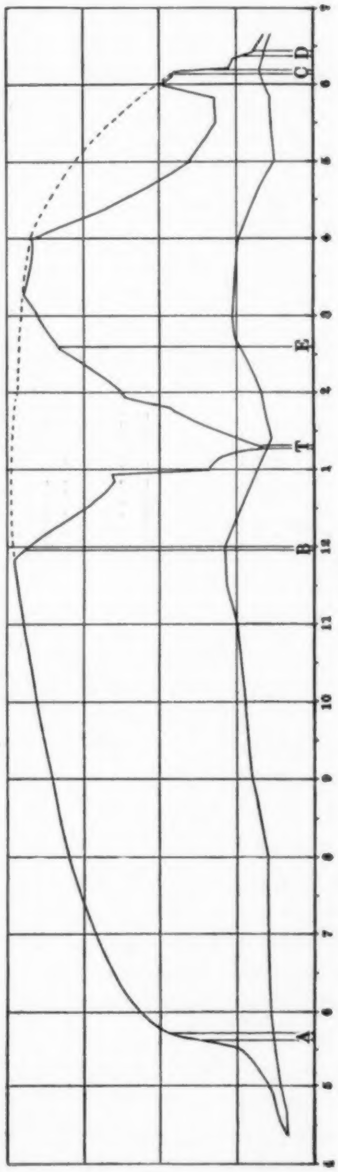


FIG. 1.

As the conductivity of the selenium changes very rapidly when illuminated, but not so rapidly when darkened, the previous condition of the cell is of special importance when the intensity of the light is on the decrease. By increasing luminosity, however, its conductivity always rises nearly to its maximum within a minute, no matter what the condition of the cell may be.

Discussion.—A study of the curves of Fig. 1 gives the following account of the quantity of sunlight on the day of the eclipse. As the morning dawn occurred in an entirely clear sky, the time of sunrise shown on the diagram may be considered typical. We see that the curve begins with a gradual slope, thus indicating the "astronomical dawn." Toward $5^h\ 15^m$ the slope begins to increase in steepness—the Sun's rays reflected and refracted by the atmosphere already strike the place: this is the "civil dawn." At about $5^h\ 37^m$

the first direct rays of the Sun fall upon the apparatus, and the conductivity of the selenium increases rapidly (point *A* on the diagram), until the whole of the Sun's disk is visible.

From now on the intensity of the sunlight is continually increasing, on account of the lessening distance it has to run through the atmosphere, until shortly before 12 o'clock, when the eclipse begins.

At the beginning of the eclipse the sky was still clear. That the selenium should already begin to react at this time (point *B* on the diagram) was entirely unexpected, since a partial eclipse does not diminish the general luminosity to an extent noticeable to the eye. Later on, of course, we might expect a diminution of light, and a sudden and precipitous loss at the moment of totality. It was therefore with no little astonishment that the galvanometer needle was seen to move immediately after the first contact, and for nearly an hour to indicate a uniformly increasing resistance.

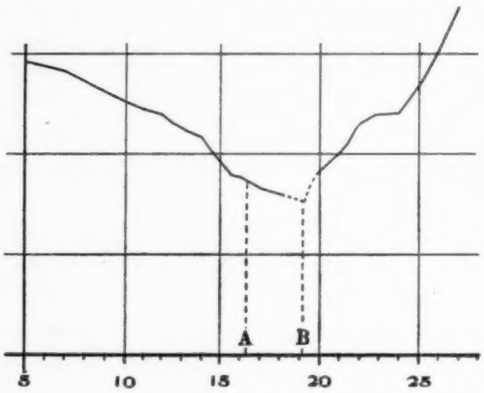


FIG. 2.

About half an hour before totality, clouds began to form and at times to cover up the Sun, thus producing the corners in the descending branch of the curve. Observations were now made in greater number in order to obtain as complete as possible a record of the variation of the light. Fig. 2 gives this part of the curve on an enlarged scale. The numbers are the minutes after 1 o'clock. The figure shows in a most interesting and instructive manner that the luminosity decreased uniformly until the darkness of totality. This latter does not show itself on the curve by a sudden descent (*A*), as had been expected; but, on the contrary, the beginning of totality was characterized by the fact that the luminosity, which had before steadily decreased, now no longer did so, but remained remarkably constant. The diagram, indeed, still shows a descent during totality, but this is owing to the selenium itself, which, as is well known, does not after an exposure to light regain its maximum resistance at once, but only after a long period of rest. For this reason, as a matter of fact, the lowest point, *B*, of the curve occurs at the end of totality, and must of necessity be indicated with extraordinary sharpness. Unfortunately no reading was taken

at the very end of totality, at $1^h\ 19^m$. It is therefore necessary to remark distinctly that the dotted part of the curve has been drawn by extrapolation, since the entire behavior of the selenium, as well as the observations to be noted in the second part of this paper, do not admit of any other course, inasmuch as no light whatever could act upon the cell between $1^h\ 18^m$ and $1^h\ 19^m$. After the period of totality there is no abrupt change in the slope, as figure 2 shows, but the strength of the current increased gradually in the same proportion as the Sun's disk was being uncovered.

However probable and self-evident the explanation given may appear, it is nevertheless entirely at variance with observations made hitherto. The question then arises how it is that the events of an eclipse appear to us so very differently. The answer is not difficult. Our eye does not perceive all kinds of luminosities with the same facility. When strong impressions are already acting upon it, it is not sensitive to small variations, but it does perceive them very strongly when the other impressions disappear. For this reason we are very sensitive to the last rays of the disappearing Sun, and the variation of the luminosity at this moment seems to us to be very much greater than during the whole time preceding. According to this explanation it would seem that our eye is the most appropriate instrument for the observation of this moment. It would be so in fact if we could also record our perceptions without loss of time. But as personal errors are different with different individuals and at different times, and especially as they are entirely beyond determination at the critical moments of an eclipse, automatic contrivances are evidently to be preferred to the eye.

As the second half of the eclipse coincided with a gradual clearing of the sky, and as a selenium cell regains its maximum conductivity only slowly, even with a strong illumination, the last contact, *E* on Fig. 1, cannot be recognized by its means.

Toward 4 o'clock in the afternoon clouds began again to form and take away a great part of the light. From about 6 o'clock until the end of the observations the sky was clear again. Sunset occurred on August 30 at $6^h\ 23^m$. But as Tortosa is surrounded, especially in the west, by a long mountain chain, which attains an altitude of 1180 meters in Mount Espina, 13 kilometers distant from the place of observation, the curve in Fig. 1 shows a precipitous descent at the point *C* shortly after 6 o'clock. It is remarkable, however, that in spite of this the astronomical sunset, *D*, is also recognizable by another rapid descent in the curve.

For the purpose of completing this investigation and bridging over the gap caused by the eclipse, these observations were repeated at the same spot on several following clear days. The results are indicated in Fig. 1 by the

dotted line. At 1 o'clock a diminution of the noon-day brightness is noticeable. The time of the greatest luminosity probably coincides exactly with that of apparent noon, but on account of what might be called the inertia of the selenium cell the measures obtained in the afternoon are somewhat too large.

The above results, expressed in terms of the conductivity of the selenium cell, were now to be transformed into those of candle-power. This was done at the Electrotechnic Institute of the high school at Aachen, by comparing

FIG. 4.

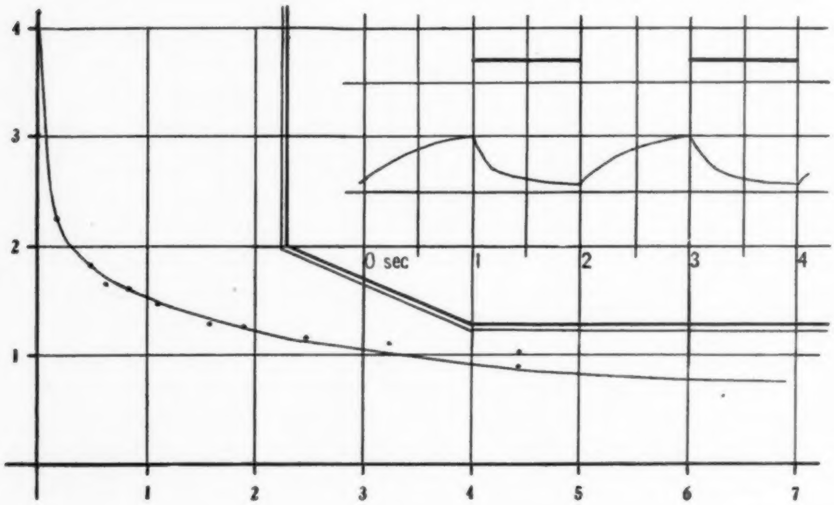


FIG. 3.

an incandescent electric lamp and a gas flame with the amylacetate lamp of the selenium apparatus. Fig. 3 gives the results, the unit used for the ordinates being 10,000 ohms and that for the abscissae 100 candle-power.

In determining the luminosity of sunlight by means of this curve, values are found which are certainly too small. Thus the maximum light shown at $11^h\ 45^m$ on Fig. 1 would be only 7000 candles, while other and direct measurements record the brightness of a Spanish noon as being much higher. The difference is owing entirely to the colors of the various lights. Thus the electric and the gas lights are especially rich in red rays, which act most strongly upon selenium; while sunlight contains much more blue and violet, which scarcely act upon selenium at all, and even the yellow and green rays, which are the strongest in the Sun, have less effect upon it. It would therefore be a great mistake to use an electric lamp to determine the conductivity

of selenium, and then to use this conductivity to find the brightness of sunlight, for this would be only to determine the brightness of those rays which act upon selenium. For this reason the numbers shown on Fig. 3 are not to be regarded as absolute, but only as characteristic of selenium. If, however, we assume that the light during totality has the same wave-lengths as the dawn, its brightness would be the same as that of the sky 30 or 45 minutes before sunrise.

II. THE INSTANTS OF THE BEGINNING AND END OF TOTALITY

The second use made of selenium during the eclipse was for the accurate determination of the instants of the beginning and end of totality. Since optical telephony shows that the conductivity of selenium changes in less than the thousandth part of a second, it became necessary to use a very rapid galvanometer, to record its performance continuously at known moments, and to employ entirely automatic and frictionless apparatus.

Apparatus.—A highly sensitive photographic film was moved with a uniform speed of 12 mm per second past a horizontal slot, through which a cylindrical lens impressed a sharp line of about 0.3 mm in width upon the film. A piece of glass ruled with lines a millimeter apart, and placed almost in contact with the film, also drew upon the latter a series of lines parallel to its length and direction of motion.

The galvanometer consisted of a steel horseshoe magnet with a silvered quartz thread drawn between its poles. The sensitiveness of this thread was such that when the current which traversed it was made or broken, less than 0.01 second sufficed to restore it to its former position. Its resistance was about 5000 ohms, but 10,000 additional ohms were inserted in series with it in order to protect it against being heated by the current. An acetylene lamp illuminated the quartz thread, and a microscope, along with the cylindric lens, projected an image of it on the photographic film.

The selenium cell, also by E. Ruhmer, was cylindrical in shape and placed in the focus of a parabolic mirror. As it was necessary to use a very feeble current in order not to injure the silvering of the quartz fiber; and as it was also desirable to vary the current as much as possible in order to increase the amplitude of the oscillations of the thread, a Wheatstone's bridge arrangement was adopted such that two selenium cells were inserted into the opposite arms of the bridge and the resistances so proportioned that the current was made to traverse the galvanometer first in one and then in the opposite direction. The battery used consisted of four large bichromate cells, and gave 8 volts and about one milliampere.

The sunlight obtained from a heliostat was first brought to a focus by

a lens. Then the divergent beam was divided, the larger part falling through green glasses upon the selenium cell, and the less through the cylindric lens upon the photographic film. When the sunlight was intercepted at the focus by an opaque screen, it was cut off simultaneously from both the selenium and the film. This arrangement, which made it possible to examine the instantaneous behaviour of the selenium cell when darkened and when illuminated, consisted of a piece of blackened sheet-metal about 4 cm square, attached to the pendulum rod of a clock, which was allowed to swing through the focus. In case the light should not have been interrupted exactly for a whole second nor symmetrically at the beats of the pendulum, the middle of the dashes drawn upon the photographic film and the middle of the vacant spaces would certainly represent the intervals of a second. A few arbitrary interruptions of the light at known times served to identify the seconds.

Fig. 4 is a diagram of a part of the photographic record. (The original was too faint to admit of reproduction.) The vertical lines represent intervals of half a second. The two upper horizontal lines were made by the clock. They are each one second long and one second apart. The lower curve was made by the selenium and the quartz fiber. The clock and selenium records differ less than 0.1 second. The figure also shows how rapidly the resistance of the selenium diminishes upon exposure, and how slowly it increases in the dark. The regularity of the motion of the film was such that no differences of 0.5 mm or 0.04 second in the lengths of the second marks were discovered. Some few lateral displacements, however, of about 0.1 second were found in several places, caused probably by the motion of the wheel-work in the chronograph. They rather facilitated the comparison of the clock and galvanometer records.

The rapidity with which the selenium reacted, and the entirely automatic and frictionless character of the apparatus, would seem to mark this method of determining the interior contacts in an eclipse as the most accurate attainable. Indeed, it held out prospects of recording not only all of the Sun's prominences, but even the shadow bands which are seen at the beginning and end of totality. But the results actually attained by this method in the present instance were sufficiently satisfactory for its first employment.

One of its main advantages lies in the fact that it can be used to some extent with a cloudy sky, when all other methods fail completely. This unfavorable condition was experienced at this very eclipse at the beginning of totality, when clouds began to form and to blur the curve on the film; in spite of this, however, the instant of the beginning of totality was re-

corded with satisfactory certainty. While it cannot be noticed on the film by the eye, a microscopic examination locates it beyond all doubt. The end of totality was of course recorded with a much greater distinctness, both because of the action of the selenium itself, and because of the disappearance of the clouds.

A diagram of the photographic film (which was too faint for reproduction) is shown in Fig. 5, in which, however, the ordinates are on a scale one hundred times that of the abscissae. The points *B* and *E* indicate the beginning and end of totality. The numbers are the full minutes after one o'clock.

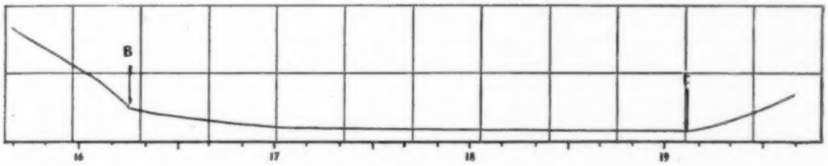


FIG. 5.

The selenium method agrees with visual observation in showing that the observed moments of totality were considerably fast of the computed ones. The following are the computed and observed times of the total phase. They, as well as all the times used in this paper, are Greenwich Mean Times, the longitude of Tortosa being $1^{m}\ 58^{s}.6$ east of Greenwich.

	Computed	Observed by Selenium Method
Beginning...........	$1^{h}\ 16^{m}\ 30^{s}.18$	$1^{h}\ 16^{m}\ 15^{s}.6$
End.................	1 19 20.51	1 19 6.9
Duration............	2 50.33	2 51.3

The results attained by this employment of selenium sufficiently show the practicability of the method. A series of such apparatus placed along the line of totality of an eclipse would not only eliminate all the personal errors of observation, but would also do away with the difficulty of determining what precise degree of obscuration was called by various observers the beginning or end of totality. While the precise moment actually recorded by the selenium cell would call for a more accurate investigation, the results would, even independently of this, be at least comparable with one another.

RECENT FORMULÆ FOR DISTRIBUTION OF SPECTRUM LINES IN SERIES

Within the last three years two spectral formulæ of some importance have been proposed to represent spectral series, one by W. Ritz in 1903, and the other by J. Halm in 1904. The first was designed to represent the series of lines found in line-spectra, while the other was intended to apply to the series of lines found in both line- and band-spectra. Both formulæ possess many advantages over the older ones.

(*a*) The formula proposed by Ritz[1] is of the form

$$\pm \nu_m = A - \frac{N}{\left\{ m+a+\frac{b}{(m+a)^2}+\frac{c}{(m+a)^2}+\text{etc.} \right\}^2},$$

where ν_m is called the wave-frequency of the line "m," and is equal to $\frac{10^8}{\lambda_m}$, if λ_m is measured in Ångström units; A, a, b, c are constants for any one series; N is the universal Balmer's constant, 109675; and m is the sequence of natural numbers, each of which is associated with one spectral line in the series. It is based to some extent upon theoretical considerations. The theory, however, as Rayleigh[2] has remarked, has the appearance of being a highly artificial one. Starting with Balmer's and Rydberg's formulæ[3] for the hydrogen series, and aided by a number of more or less arbitrary assumptions, Ritz arrives at the following expression for all substances which give line-spectral series:

$$\pm \nu = N \left\{ \frac{1}{p^2} - \frac{1}{q^2} \right\},$$

where p and q are roots of certain transcendental equations, and are expressible in the form of the semi-convergent series, $p=n+a_1+\frac{b_1}{p^2}+\ldots$ and $q=m+a_2+\frac{b_2}{q^2}+\ldots$. If, as a first approximation, we put $p=n+a_1$ and $q=m+a_2$, we obtain Balmer's and Rydberg's formulæ. As a second approximation we obtain

$$\pm \nu = N \left\{ \frac{1}{\left(n+a_1+\frac{b_1}{n^2}\right)^2} - \frac{1}{\left(m+a_2+\frac{b_2}{m^2}\right)^2} \right\}.$$

[1] *Ann. der Phys.*, (4) **12**, 264, 1903.

[2] *Phil. Mag.*, (6) **11**, 122, 1906.

[3] Kayser, *Handbuch der Spectroscopie*, **2**, 504, 570, 572. Ritz, *Ann. der Phys.* (4) **12**, 266, 1903.

If n is taken as constant, this becomes

$$\pm\nu = A - \frac{N}{\left(m + a_2 + \frac{b_2}{m}\right)^2} .$$

It is in this form that the formula was applied in practice. Upon incorporating in it the relations discovered by Rydberg[1] to hold between the principal and second subordinate series, a single formula is obtained for the two,

$$\pm\nu = N\left\{\frac{1}{\left(n + a_1 + \frac{b_1}{n^2}\right)^2} - \frac{1}{\left(m + a_2 + \frac{b_2}{m^2}\right)^2}\right\} ,$$

where $m=1.5$, $n=2, 3, 4, \ldots$ for the principal series, and $n=2$, $m=1.5, 2.5, 3.5, \ldots$ for the second subordinate series. In this form it also represents the first subordinate series except that the constants a_2, b_2 are different and $n=2$, $m=3, 4, 5, \ldots$ The values which n and m assume here for the three series are the same as those used by Balmer and Rydberg[1] in their formulæ for the hydrogen series.

There are a number of advantages of the Ritz formula over the others: (1) it makes N a universal constant for line-spectra; (2) it involves fewer constants, six for the *three* series instead of nine as required by the Kayser and Runge formula: (3) it is compatible with the identical magnetic behavior[2] and intensity relations so far observed in the case of the principal and second subordinate series; and (4) it most accurately represents the data so far as it has been applied. To give some idea of its relative accuracy when compared with the Kayser and Runge formula, the following table has been taken from Ritz's article[3] (it is typical of similar comparisons which he made for the other elements):

LITHIUM

PRINCIPAL SERIES

m	λ	ν	F	K. and R.	Ritz
2	6708.2	14903.1	0.2	+108.0	0.00*
3	3232.77	30924.4	0.03	0.00*	0.00*
4	2741.39	36467.3	0.03	0.00*	0.07
5	2562.60	39011.5	0.03	0.00*	0.00*
6	2475.13	40390.0	0.1	−0.2	0.20
7	2425.55	41215.5	0.1	−0.01	0.01
8	2394.54	41749.3	0.2	+0.3	0.03
9	2373.9	42112.0	—	+0.75	0.10
10	2359.4	42370.7	—	+1.18	0.22

[1] Rydberg, Paris Reports, **2**, 212, 1900. Ritz, *Ann. der Phys.*, (4) **12**, 270, 1903.

[2] Runge and Paschen, *Astrophysical Journal*, **20**, 123, 1904.

[3] *Loc. cit.*

SECOND SUBORDINATE SERIES

m	λ	ν	F	K. and R.	Ritz
1.5......	6708.2	14903.1	0.2	+615.0	0.00
2.5......	8127.3	12300.8	——	−65.0	0.75
3.5......	4972.11	20106.7	0.1	0.00*	0.00*
4.5......	4273.44	23393.8	0.2	0.00*	−0.08
5.5......	3985.94	25081.2	0.2	0.00*	−0.04
6.5......	3838.3	26046.0	3.0	−0.2	+2.1

Tail of Principal Series (ν_∞) = 43482.8
Tail of Second Subordinate Series (ν_∞) = 28579.7

In this table the symbols m, λ, ν are respectively the index-number, wave-length, and wave-frequency of the series-lines; F is the experimental error; and "K. and R." and "Ritz" stand for the difference (observed λ−calculated λ), as determined respectively by the two formulæ. The lines marked with a star were used to calculate the constants of the formulæ. All the data given were taken by Ritz from Kayser's *Handbuch der Spectroscopie.*

The table shows that the Ritz formula has a marked advantage in accuracy over the Kayser and Runge formula, especially for the lines at the red end of the series. That the formula satisfies the Rydberg relations is shown in the table by the facts that both series start with the same line and that the wave-frequency distance between the tails of the two is equal to the wave-frequency of the first line in the principal series. It is interesting to note that the second line in the second subordinate series lies to the red side of the first line in the same.

The foregoing formula led Ritz to predict the positions of certain lines in the spectra of the alkali metals. Last year Saunders[1] found that of his new lines two coincided very closely with Ritz's predictions.

(b) The formula proposed by Halm[2] to represent the series in line- and band-spectra was an empirical one. It is as follows:

$$\frac{1}{\nu_\infty - \nu_m} = a(m+\mu)^2 + b \ ,$$

where ν_m is the so-called wave-frequency of the line "m" in the series; a, b, ν_∞ are constants for any one series, ν_∞ being the wave-frequency of its tail; and μ is some constant, usually zero. Because it is a modification of Rydberg's[3] line-series formula and Thiele's[4] band-series formula, he called it the "Rydberg-Thiele" formula. He applied it to all of the known series of line- and band-spectra, and found it to hold in most cases within the errors of observation. In those *line-series* where the agreement was not

[1] *Astrophysical Journal*, **20**, 188, 1904.

[2] *Edin. Trans.*, **41**, III, 555, 1905.

[3] Kayser, *Handbuch der Spectroscopie*, **2**, 516. [4] *Ibid.*, **2**, 483.

good his formula still represented the data as well as, or better than, the Kayser and Runge formula. He evidently did not know of the Ritz formula, for in his comparisons he does not refer to it, and yet it represents the data (so far as it has been applied) uniformly better than his own. For line-series the Ritz formula has all of the advantages, mentioned under (*a*), over the Rydberg-Thiele formula; for the latter only approximately satisfies the Rydberg relations and, as a rule, requires twelve constants for the three series.

In applying the formula to band-spectra all of the known series of carbon and oxygen were tried, and the formula was found to represent them to within a few hundredths of an Ångström unit. The greatest number of lines in any of these series did not exceed fifty. When applied to the cyanogen band at $\lambda=3883$, which contains 170 lines, the agreement, Halm says, was excellent up to the 80th line, quite satisfactory up to about the 140th, but beyond this the discrepancies increased enormously, showing that the formula was not applicable to the whole band. Upon dividing the band into three parts, or branches, he found that each branch could be accurately represented by the formula. His results show, however, that, as in the case also of some of the other carbon and oxygen bands, the index-number of the first visible line in the series is a comparatively high number, showing that, apparently, many lines in the series are missing.

On the basis of Lester's[1] work on the oxygen bands, Halm is led to conclude that this cyanogen band is made up of three branches which overlap, but with the result that one of them apparently obliterates the other in the region common to the two. This sudden dropping off on the head side, or tail side, of a band-series is not rare. Nevertheless it does not seem to me to be the case in this cyanogen band, for, if it were, we should not expect the uniform decrease in intensity from one end of the band to the other.

While not so good for line-series as the Ritz formula, the Rydberg-Thiele formula is undoubtedly the best formula for band-series so far proposed. It serves also to emphasize the close relationship existing between line-spectra and band-spectra.

T. S. Elston.

Johns Hopkins University,
February, 1906.

[1] *Astrophysical Journal*, **20**, 81, 1904.

THE ASTRONOMICAL AND ASTROPHYSICAL SOCIETY OF AMERICA

The seventh meeting of the society was held in New York City on December 28, 29, and 30. Papers were read at four well-attended formal sessions, with the president of the society, Professor Newcomb, in the chair. The list of papers presented is as follows:

David Todd, "*Saturn* as Seen with the Eighteen-Inch Clark Refractor of the Amherst College Observatory."

S. I. Bailey, "Some Variable Star Problems."

Annie J. Cannon, "Maxima and Minima of Variable Stars of Long Period."

E. C. Pickering, "Systematic Study of Faint Stars."

G. C. Comstock, "Distribution of the Stars."

F. H. Seares, "Photometric Investigations."

Mrs. W. Fleming, "Some Peculiar Stellar Spectra."

Eric Doolittle, "The Hough Double Stars."

E. B. Frost, "Professor Burnham's Forthcoming General Catalogue of Double Stars."

C. L. Poor, "The Figure of the Sun."

J. A. Parkhurst and F. C. Jordan, "Photographic Photometry of Rapidly Changing Variable Stars."

S. A. Mitchell, "Results from Spectrograms at the Spanish Eclipse, 1905."

E. B. Frost, "Observations of Radial Velocities of Stars."

G. H. Peters, "Solar Coronas Observed at the Porta Coeli Station of the U. S. Naval Observatory Eclipse Expedition, 1905."

N. E. Gilbert, "Polarized Light in the Corona, Eclipse of 1905."

C. C. Trowbridge, "Resemblances between Persistent Meteor Trains and the Afterglow from Electrodeless Discharges."

E. E. Barnard, "Vacant Regions of the Sky."

G. C. Comstock, "A Proposed Method for the Wholesale Determination of Velocities in the Line of Sight."

E. C. Pickering, "Determination of Absolute Positions of Stars by Photography."

D. Todd and R. H. Baker, "Local Predictions for the Total Eclipse of 1907 in Turkestan and Mongolia."

J. A. Brashear, "On Some Evidences of Permanent Set in Optical Surfaces."

F. H. Seares, "The *Polaris* Vertical Circle Method of Determining Time and Azimuth."

Eric Doolittle, "Determination of the Errors of Adjustment of the Polar Axis of the Equatorial."

David Todd, "On the Practical Requisites for Securing Perfect Definition in Eclipse Photography."

E. B. Frost, "Observations of Sun-Spots by the Late C. H. F. Peters."

D. Todd and R. H. Baker, "Computed Tracks and Totality-Durations of Total Solar Eclipses in the Twentieth Century."

A. O. Leuschner, "An Analytical Method of Determining the Orbits of Satellites."

W. H. Pickering, "The Theory of Planetary Inversion."

C. G. Abbot, "A Standard Pyrheliometer and its Use on Mount Wilson, California."

B. L. Newkirk, "Tables for the Reduction of Photographic Measures."

R. T. Crawford, "A Contribution on Astronomical Refraction."

Sarah F. Whiting, "A Solar Planisphere."

B. L. Newkirk, "Investigation of the Repsold Measuring Apparatus of the Students' Observatory."

W. W. Dinwiddie, "The Forty-Foot Camera of the U. S. Naval Observatory Eclipse Station at Guelma, Africa."

C. D. Perrine, "Polarization Observations of the Corona of August 30, 1905."

F. Schlesinger and G. B. Blair, "Note on Anomalous Refraction."

Henrietta S. Leavitt, "New Variable Stars in the Small Magellanic Cloud."

R. S. Dugan, "Magnitudes and Mean Positions of 359 *Pleiades* Stars."

David Todd, "Results of Amherst Eclipse Expedition to Tripoli, 1905."

M. B. Snyder, "The Philadelphia Observatory and the Disastrous Fire of March 9, 1905."

LETTER FROM PROFESSOR CALLENDAR

My attention has been called to a statement by Mr. G. T. Walker contributed to the Oxford meeting of the International Union for Co-operation in Solar Research with regard to one of my Sunshine Recorders, which does not appear to represent the facts. I had no opportunity of correcting this statement at the time, and it has received very wide circulation among those interested in the subject without contradiction. In view of the importance of a full discussion of all promising methods of recording the solar radiation, I trust you will be able to allow me space for a reply.

Mr. Walker complains that a particular instrument of the old type with removable cover made in 1898 has been damaged by condensation of water

vapor, that the black has peeled off the wires, and that the constants of the instrument have altered. I have looked up the case of this particular instrument, and can only conclude that Mr. Walker has been misinformed. I find a letter from the observer in charge, dated February 1902, stating that the apparatus was working extremely well. Neary two years later it was returned to England for the redetermination of its reduction factor, which the makers had omitted to supply in the first instance owing to some misunderstanding. *The instrument was found to be in perfect condition, the coating of black on the wires was quite uninjured, and there was no evidence whatever of any alteration in its reduction factor.* We do not, as a matter of fact, recommend this type of receiver for use in damp climates, because, not being hermetically sealed, there is risk of damage from condensation, in case the observer in charge omits to renew the drying material periodically according to instructions. The hermetically sealed type is certainly preferable in this respect, but is open to the objection that it cannot so easily be repaired in case of damage in transit. But if, as Mr. Walker states, water was allowed to collect and drop on the wires, it is certainly surprising that the instrument should have endured such treatment for so long a time without any evidence of alteration. It seems unfair, however, to blame the instrument or condemn the method.

H. L. CALLENDAR.

ROYAL COLLEGE OF SCIENCE,
LONDON, S. W.,
October 26, 1905.

NOTE ON PROFESSOR NEWCOMB'S OBSERVATIONS OF THE ZODIACAL LIGHT

Professor Newcomb's paper on the zodiacal light north of the Sun in the October number of this *Journal*, has interested me much, and I have wondered if certain observations made here do not have reference to the same phenomenon. At the summer solstice the Sun passes 24° below our north horizon at midnight. The old assumption that twilight ends when the Sun is 18° below the horizon would not permit any twilight effect here at midnight. Yet every summer that we have been here I have observed for a week or two in midsummer a twilight glow passing along the north horizon for a couple of hours in the middle of the night. I have watched this move from the west under the pole to the east, being apparently the evening twilight passing along the north horizon to join the dawn. This extends several degrees above the horizon at midnight. The extent along the horizon may at that time be as much as 15° or 20°. In explanation of this I had

assumed that the twilight effect was not really confined to the 18° limit, and that it must extend at least 30° from the Sun.

I have thought, since reading Professor Newcomb's article, that what I have seen is probably identical with what he observed in Switzerland; and therefore it may possibly be a zodiacal effect. Hereafter I shall make special observations of the phenomenon, to try to decide whether it is purely atmospheric twilight or a manifestation of the zodiacal light. The phenomenon is in no wise a difficult one to observe.

After I had communicated with Professor Newcomb on the subject, he kindly suggested that the following note be appended to mine.

E. E. BARNARD.

YERKES OBSERVATORY,
January 17, 1906.

NOTE BY PROFESSOR NEWCOMB

There is of course no absolute proof that the light visible along the north horizon at midnight, when the Sun is at a depression of 25°, more or less, is not a form of twilight. The phenomena of meteors show that the atmosphere, or an atmosphere of some kind, surrounds the earth to a height of more than 100 or perhaps 200 miles. The reflection of the Sun's rays from this rare atmosphere would produce a similar effect; but I think this is not the cause of the phenomena, for these reasons:

1. Careful observation when the zodiacal light makes the greatest angle with the horizon show that as the horizon is approached, its breadth rapidly increases at such a rate as, if continued, would bring it far enough north of the Sun to be visible under the circumstances we have mentioned.

2. The rapid diminution and disappearance of twilight when the Sun is somewhere between 15° and 18° below the horizon seems to show that this is the end of actual twilight.

Reviews

Spectroscopy. By E. C. C. BALY. London and New York: Longmans, Green & Co., 1905. Pp. xi + 568, with 163 figures. $2.80.

The appearance of this volume in the series of "Textbooks of Physical Chemistry," edited by Sir William Ramsay, reminds one that, in its earlier days, spectroscopy was largely, if not primarily, a branch of chemical science. So true was this at least that, in 1886, chemists reckoned among the noteworthy properties of the then newly discovered *germanium* the fact that it was *not* discovered by use of the spectroscope. But one has only to turn the pages of the present volume to be impressed with the wide divergence between the "spectrum analysis" of Bunsen's time and the spectroscopy of the present; for its pages bristle with mathematical formulæ and mechanical considerations which chemists used to regard as *foreign* but which they now label *domestic*.

Briefly the volume may be described as an excellent scholarly compendium of terrestrial spectroscopy brought up to date. The subject of astrophysics is barely touched upon. Of the seventeen chapters which the treatment includes, the first seven are devoted to what might be called ordinary spectroscopic practice, including the theory and use of the prism and the diffraction grating; the remaining ten chapters are given to more advanced and special problems, such as those occurring in the infra-red and ultraviolet regions, spectroscopic sources, the Zeeman effect, spectral series, etc. Concerning each of these chapters it may be said that the problem is always definitely stated, the English is clear and simple, and the references to original sources are ample.

Besides having given a rather extended description of apparatus, the author has woven into the text, in an interesting manner, practically all of the established principles of the subject. Nor, indeed, has he limited himself to *known* principles; for many mooted points and needed investigations are suggested.

The chapters on "Series," on "The Zeeman effect," on "Interference Methods," on "Spectrum Photography," and on "The Infra-Red" appear especially valuable; they have a "practical" air about them such as might be expected from a man who has spent much time in experimental contact with the subject. But the two chapters on "The Production of Spectra"

and on "The Nature of Spectra"—to which the author's own work has contributed so largely—are possibly the most interesting ones in the entire book. They contain important suggestions for anyone working in the optical laboratory. The complete details and precautions given for filling vacuum tubes will be appreciated by many.

The following remark on p. 36 needs correction in any future edition: "Rowland was led to his work on gratings by his invention of a very accurate method of cutting a screw, which, of course, is the basis of all dividing engines such as are used for ruling gratings." It is generally considered a matter of history that the sequence of ideas was just the reverse of this. In his search for monochromatic illumination(in a study of phosphorescence, as your reviewer has heard it) Rowland saw that a good grating was a necessity. The key to a good grating he recognized in a perfect screw; and hence set to work to make one.

As to the eight pages (166–174) devoted to the theory of the concave grating, one can hardly avoid feeling that these might well be replaced by the more elegant and simple treatment given by Runge in Winkelmann's *Handbuch der Physik.*

The spark-coil, or open magnetic circuit transformer devised by Rowland in 1886 and represented in Kayser's *Spectroscopie*, Bd. I, p. 183, Fig. 39, is so easily made, and is such a powerful and useful source, that its description might well find place in any chapter on production of Spectra.

The section on "The Reversal of Spectral Lines" is excellently illustrated by one of the author's own photographs. The explanation, based on experimental evidence, which Humphreys (*Astrophysical Journal* **18**, 204, 1903) has offered for double reversals, and his opinion that true double reversals "seldom, if ever, occur in arc spectra," would have added interest to this paragraph.

The volume as a whole is characterized by a fine perspective and by always putting the emphasis in the right place. It should find a place in the library of every student of physical optics.

HENRY CREW.

Beiträge zur Photochemie und Spectralanalyse. By J. M. EDER and E. VALENTA. Halle: Wilhelm Knapp, 1904. Pp. xvi+858; with 93 figures in the text and 60 plates, 25 in heliogravure. Bound, M. 25.

This massive volume renders available to the general scientific public the valuable series of papers which have been contributed by the authors, for the most part to the Vienna Academy of sciences. The work is divided

into five parts: I, spectroscopic investigations; II, sensitometry and photometry of the chemically active rays, and solarization; III, behavior of the silver salts to different parts of the spectrum; IV, spectroscopic studies of the photographic three-color printing; V, investigations of printing colors.

The spectroscopist and physicist will find the work of very great service, particularly the first part, which contains in 418 pages (of size 17×25 cm) the authors' well-known researches upon the spectra of the elements, in which the wave-lengths are given in clear tabular form, with the results of other observers for comparison. The reproductions of spectra represent the highest perfection of the art, and were executed in the *k.k. Graphischen Lehr- und Versuchsanstalt* in Vienna, of which the authors are respectively director and professor. The first paper is dated as presented to the Academy in 1890, and the last paper, which discusses the invariability of wavelengths in the spark and arc spectrum of zinc, was communicated to the Academy at the end of 1903.

Some of the longer papers in this part deal with the following topics: on the visible and ultra-violet emission spectrum of faintly luminous hydrocarbons (the Swan spectrum) and of that of the oxy-hydrogen flame; on the utility of the spark spectra of different metals for determining the wavelengths in the ultra-violet; on the line-spectrum of elementary carbon; on the different spectra of mercury, and the spectra of copper, silver, and gold; spectroscopic investigation of argon; the spectra of sulphur; normal spectra of certain elements for wave-length determinations in the extreme ultraviolet.

The second part, devoted to photographic effects of light, which occupies 174 pages, presents investigations of very high value to all who are making scientific applications of photography. Among the topics treated in the different papers are the following: new chemical photometer for the ultraviolet rays in daylight; investigations on the chemical action of light; determination of the sensitometry of orthochromatic plates with Scheiner's sensitometer; a system for the sensitometry of photographic plates (in four sections); phenomena of solarization in spectrum photography. Mention should be made of the beauty of the reproductions of the opacity-curves for photographic plates given in this section, in which the squares of the coordinate paper are printed in blue.

Many of the papers in Part III were published in the *Photographische Correspondenz*, and a few brief papers were contributed by others than the authors. The authors have also added some papers which had not appeared elsewhere. The field is one in which the authors speak with

eminent authority, and this part will be of great utility to technical photographers, and others interested in the correct rendering of colors. Among the topics treated are: behavior of the halogen compounds of silver in respect to the solar spectrum; spectrographic investigation of standard sources of light; on methods of photographing the spectrum with bromide of silver plates; investigations of the sensitizing power of different coal-tar products for bromide of silver dry plates; the action of different yellow dyes as sensitizers. Diagrams are given in the text whereever needed, and the processes and instruments employed are described in a clear manner. It is a cause for congratulation to all workers in the fields touched upon in this volume that, through the particular official relationship of its authors, this splendid volume can be issued at the price of 25 marks, which is insignificant as compared with the normal cost of publication. The type is all of the beautiful font which makes the reading of the publications of the Vienna Academy a particular pleasure. No spectroscopist or student of scientific photography can afford to be without this book, and the very few libraries (if any), which may contain all of the published works of the authors, need have no fear of duplication in securing this superb volume, representing the collected works of these Austrian savants.

E. B. F.

Mathematical and Physical Papers. By G. G. STOKES. Volume V. Cambridge: The University Press; New York: The Macmillan Co., 1905. Pp. xxv + 370, with portrait.

This volume concludes the reprint of the scientific papers of the late Professor Sir George Gabriel Stokes. The first volume of these reprints appeared in 1880, and we now have in these five volumes practically every scientific paper of Stokes. Various semi-popular lectures given at various occasions have been omitted, but no important printed contribution has been overlooked.

This fifth volume of Stokes's papers has been prepared for the press by Dr. Larmor, and has been enriched by a biographical sketch of Stokes which was contributed by Lord Rayleigh to the obituary of the Royal Society, by a photographic portrait, and by a series of examination papers and problems which had been set at various times by Stokes in the University of Cambridge.

In this volume there are not many papers of special interest to investigators in spectroscopy, although it contains the Wilde lectures on the nature of the Roentgen rays, the interesting memoir on the crystalline reflection of

crystals of chlorate of potash, and many shorter papers on questions dealing with the intensity of solar radiation.

To the student of physics every paper in the volume is of interest, and not the least so are the various facts either in the text or in notes by Dr. Larmor in cônnection with the examination questions. To one interested in the history of mathematics and physics the volume is of the greatest importance. The biographical sketch of Stokes by Lord Rayleigh is one of the most interesting and important contributions to the history of physics that have appeared in recent years, and the appreciation in it of the relative value of Stokes's contribution to knowledge is most interesting.

J. S. AMES.

Newcomb-Engelmanns Populäre Astronomie. Dritte Auflage. Herausgegeben von DR. H. C. VOGEL. Leipzig: Wilhelm Engelmann, 1905. Pp. x + 748. Figs. 198, including 12 plates. 15 Marks; bound, 16 Marks.

This is the second edition of this admirable work which has been prepared by Director Vogel of the Astrophysikalisches Observatorium at Potsdam, and it has been enlarged and revised to include all important researches of the ten years which have elapsed since the previous edition appeared. Based upon the best modern popular astronomy for serious-minded readers, the revisions and enlargements which it has undergone make it easily the best reference work available on astronomy and astrophysics. It can be especially commended to workers in allied branches of science and to the general reader as representing a judicial and sufficiently complete statement of the present known facts of astronomy.

There has been no attempt to make the work popular in the sense of giving a superficial treatment, although of course no mathematical knowledge is presupposed on the part of the reader. The work does not assign to each fact or discovery the name of the investigator, which will doubtless prove to be a decided convenience to the non-technical reader, to whom questions of priority are not matters of importance.

Additional value has been lent to the book by the co-operation of the reviser's friends. Thus Professors Dunér and Küstner examined the second edition carefully and made suggestions for the new edition. Professor Young contributed his views on the constitution of the Sun, as he did to Professor Newcomb's original work in 1877. Professor Seeliger has written a section on the structure of the universe; and Professor Kapteyn also gave to Professor Vogel an expression of his views on the same sub-

ject. Messrs. Kempf, Eberhard, and Ludendorff also rendered important assistance in the preparation of the new edition.

The illustrations are excellent; many of them are new. The tabular statements, which occur in various parts of the work, are fully brought to date and will prove of value to professional astronomers. The list of proper motions exceeding $1''$ on pages 510 to 512 is a case in point; other valuable tables are those of binary stars whose orbits have been determined; also those of spectroscopic binaries.

Brief biographical sketches of deceased astronomers occupy the last fifty pages of the book, and add to its value. An appendix contains tables of the elements of the planets and comets, and lists of the brighter variable stars, binary stars, double stars, nebulæ, and clusters.

It is to be hoped that the distinguished author of the original work may feel disposed to give us a new edition in English; for this edition in German, after these revisions at the hand of one of the most eminent living astrophysicists, is lacking only in its availability for those who do not readily read the German language.

F.

Manual of Advanced Optics. By C. RIBORG MANN. Chicago: Scott, Foresman and Co., 1902. Pp. 196; with 41 figures. $2.

There has existed the serious need of a book dealing with those methods of measurement that are based on the interference of light-waves. One has been compelled in the past to depend upon the rather meager descriptions of these methods that are given in the original articles. The present book to a large degree fulfills this need. It is divided into eighteen chapters, and has a short appendix and an index. The first six chapters deal with optical measurements by the direct use of interference patterns. The subjects treated are: limit of resolution, the double slit, the Fresnel mirror, the Fresnel bi-prism, the Michelson interferometer, and the visibility curves. The next four chapters take up the use of the prism and grating. Chapters eleven to fifteen inclusive cover experiments on the subject of polarized light, while the sixteenth treats of spectrophotometry. The last two chapters deal with the interesting subjects: "The Development of Optical Theory" and "The Trend of Modern Optics." The appendix contains tables and a description of some necessary laboratory manipulations.

Each chapter begins with a brief treatment of the theory involved and emphasizes the physical principles rather than the mathematics. This is followed by concise directions for performing the experiments and the

results of an actual trial. There are many references to the original literature, and, although one wishes the lists were more complete, it is much better than most books in this respect. The diagrammatic drawings given to illustrate the text are largely new.

Being written by one who has actually been over the ground himself, the book points out many of the details of the manipulations that often cause much trouble, but are not mentioned in the original articles. The bock covers a field quite distinct from that of the other laboratory manuals ot optics, and represents the work offered as a twelve weeks course in advanced optics at one of the principal optical laboratories of this country.

A. G. S.

Die optischen Instrumente: aus "Natur und Geisteswelt," Sammlung wissenschaftlich-gemeinverständlicher Darstellungen, 88ste Bändchen. Von DR. MORITZ VON ROHR, Leipzig: B. G. Teubner, 1906. Pp. v + 130. Bound, M. 1.25.

Dr. von Rohr's book is written in an interesting and popular style, and covers the subject probably as well as any descriptive work can do. The small size of the book and the general plan of the series to which it belongs naturally limit it in scope, but within its limits it is well arranged, and many of the interesting facts of optics are touched on, if not analyzed. First after the discussion of elementary considerations concerning lenses, including the effects of diaphragms variously located, Dr. von Rohr explains the action of the eye as an optical instrument, and states some of the principles governing binocular vision. Other optical instruments Dr. von Rohr divides roughly into objective (those where the lens is used simply to project the image of an object; as in the photographic camera, the stereopticon, and the cinematograph), and subjective (those in which the lenses are arranged and designed expressly for use with the human eye; as in the reading-glass. the telescope, and the microscope).

The various kinds of aberration that may occur in lenses are described, and the various types of lenses are discussed much in the same way as in Dr. von Rohr's larger book on the theory and history of the photographic objective. The historical development of the photographic objective is traced, and when credit is given to the great German opticians for new designs, a special tribute is also paid to the Americans—to Clark for his great refractors and to Brashear for his astrophotographic lenses. Considered in its entirety, Dr. von Rohr's book is well worth reading and, if translated into English, would be used to supplement the textbooks of the classes in physical science throughout the United States.

It is to be regretted that in this work, as in many others, the discussion of the mathematical side of the subject is omitted. A complete work on the theory of lens-design is much needed at the present time. The indifference with which students of optics and designers of optical instruments work through a long trigonometrical calculation to determine the constants of a lens, and the eagerness with which they seize upon and apply the fragmentary articles in the scientific journals giving developments of Abbe's theory of optical invariants, seem to show that there is a growing demand for a handbook containing such tables that the computer can choose as given quantities, the conditions of field or achromatism a lens is to satisfy and be led to its glass, thickness, and curves as quickly and unerringly as the user of a steel company's handbook is led to the selection of material to use in bridge or building design. STANLEY C. REESE.

PITTSBURG, PA.

An Introduction to the Study of Spectrum Analysis. By W. MARSHALL WATTS. London and New York: Longmans, Green & Co., 1904. Pp. 325; with 135 figures and one colored plate.

This small book doubtless grew out of the author's *Index to Spectra*, but it does not displace that useful compilation, although nearly one-half of this work is devoted to a catalogue of spectra. The first impression one gets of the book is that it is decidedly lacking in balance: possibly a sufficient number of topics are treated, but the relative attention devoted to different matters does not commend itself. The book is not in the same class with Baly's *Spectroscopy*, elsewhere reviewed in this number. The 184 pages of descriptive text are subdivided into 14 chapters. The illustrations are for the most part good, many are quite familiar, and but few are original. Some cannot be regarded as exactly called for in a work treating of spectroscopy—for instance, several pictures of comets, of nebulæ, and of the nebulosity about *Nova Persei*. The book contains no mathematics, a respect in which it may perhaps the better suit the general reader. The principal sections are as follows: "How to Produce a Spectrum;" "Flame-Spectra;" "Spectra Produced by Means of Electricity;" "Absorption Spectra—Electric Arc" (the reason for the juxtaposition is not obvious); "The Diffraction Spectrum—Measurement of Wave-Lengths;" "On the Production of Dark Lines by Absorption—The Fraunhofer Lines of the Solar Spectrum." Celestial objects are treated in about 50 pages. The concave grating is described quite inadequately. The numerical relationships in wave-lengths in spectra are treated at some length. It is not clear here why the author included in the spectrum of hydrogen a number of the brighter

lines of the so-called second spectrum. Spectral relationships have not as yet been given for these, and the author's purpose would have been subserved if the others had been omitted or collected together by themselves. Band spectra, the spectroheliograph, the Zeeman effect, and the Michelson echelon are briefly discussed.

The catalogue of spectra gives the wave-lengths of certain lines for most of the elements, but no explanation is made of the source from which they are derived, or of the principle on which the fainter lines are omitted. A comparison with the author's *Index* shows that the wave-lengths are rounded off from values there assembled. The omission of some explanatory paragraphs in regard to this catalogue of spectra is certainly surprising. The table gives in three columns the wave-lengths, to only the first decimal of the tenth-meter, and numerical data as to intensity in character in the arc and spark, though it is not stated on what scale the intensities are assigned. In many cases a numeral is given in parenthesis under the wave-length. Comparison with the *Index* indicates that this denotes the number of lines omitted between that and the following line. If compactness of the tables had been any object, nearly one-half of the space could have been saved by putting these parenthetical data in a separate column.

An appendix reprints papers by Sir William and Lady Huggins on the relative behavior of the H and K lines, and on modifications of the magnesium line at λ 4481 under different laboratory conditions. It is to be hoped that the author's wish may be fulfilled, that the book may prove a useful guide to "those who have only the simplest means;" it is hardly expected that the work will be of large value to those whose libraries contain the technical works on spectroscopy.

E. B. F.

Handbuch der geographischen Ortsbestimmung für Geographen und Forschungsreisende. Von ADOLF MARCUSE. Braunschweig: Friedrich Vieweg und Sohn, 1905. Pp. x+341; 54 figures and 2 star charts. Bound, M. 12.

This book is intended primarily for the use of explorers who may desire to ascertain their geographical position on the earth by means of astronomical observations. We should, therefore, expect to find an extremely simple and brief explanation of elementary principles in spherical and practical astronomy, together with an ample collection of auxiliary tables. But it does not appear that the author has presented his material in an unusually attractive or otherwise novel form, nor has he appended any tables except an abbreviated one for the so-called "Mercator functions." We should have expected to find, for instance, specimen parts of the important ephe-

meris pages printed in the book, with illustrative examples of time and latitude computations for which the ephemeris quantities were taken from these specimen pages.

We shall not consider the volume with much detail from the above rather uninteresting point of view, however, because an English-speaking reviewer is likely to be rendered hypercritical by the great excellence of our existing treatises on practical astronomy. But surely we might expect this volume to give prominent space to the measurement of geographical position in exceptional cases of unusual difficulty not considered in previous textbooks. For instance, why do we not find an example, completely worked out, of a latitude determination near the pole? How did Nansen make sure he was "farthest north"? He must have observed the arctic Sun when its altitude changed but little in many hours, and when stars were altogether invisible. Nansen's actual observations under these circumstances would be of great interest, and would have been in their proper place as an example in this work.

Again, for azimuth, the author advises observations of *Polaris* in the northern hemisphere, and of certain less favorable polar stars in the southern. How about travelers in the equatorial regions, where no polars can be observed on account of proximity to the horizon? How are ordinary meridian altitudes observed when the Sun's declination at noon is almost equal to the latitude, when for a number of minutes no one can tell within a quadrant or two which point of the horizon is under the Sun?

The book contains many such things. There is a chapter on observing with strings and stones, in case all angle-measuring instruments should be lost; but there is no mention of the method of measuring latitude by the duration of sunrise. This last method can even be used without any ephemeris. On page 241 there is a sextant example of which the venerable observations were made in 1808, yet this book is surely the most modern treatise on the very latest thing in astronomy—balloon navigation. The instrument used in measuring altitudes from the car is a modification of Abney's level, the angle being read from a quadrant after bringing the Sun, seen through a small telescope, into coincidence with the reflection of a level bubble. Reductions are made by means of Sumner lines, and the results of a number of actual observations are given. We strongly suspect, however, that the navigating officer of the good balloon "Brandenburg" reduced his observations after the vessel had not only been anchored, but actually folded up and laid away after letting out her gas.

We recommend this volume to the librarians of all well-equipped balloons. J.

ERRATA

In the January number Fig. 2 of Plate IV, illustrating the article by Messrs. Hale and Adams, should be inverted. As printed, the end of longer wave-lengths is on the left-hand side instead of the right-hand side as indicated by the legend.

The legend under Fig. 1 of Plate V should read "Region λ 5150—λ5230" instead of "Region λ5150—λ5270."